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ABSTRACT

This publication, designed for educators, researchers, and university students, includes articles of theory, opinions, research and practical application pertaining to all levels of educational practice. The first two articles define the place of science in the curriculum, first as a basic study and then as a holistic study. The next three articles examine the implications that Piaget, Piagetian Studies, teaching models, aptitudes, and technology have for improving science instruction and student learning. The last five articles treat some persistent problems and describe some possible solutions: (1) science content selection; (2) science for the handicapped; (3) readability problems; (4) the preservice science preparation of elementary teachers; and (5) closing the widening gap between research and practice. (Author/GA)

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this issue:

science education: a probe for tomorrow

Hans O. Andersen, guest editor

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From the Editor

The sixties are past, and soon we must face the challenge of the eighties. The alphabet science curricula which once commanded our full attention are again being scrutinized. Many of the good curriculum ideas have been incorporated into new programs and revised texts. However, it appears as if teachers are taking a step backwards—back to the basics and textbook science. As we move back to the basics questions are forming in the minds of most serious educators. Why go back? Can we not go forward to the basics? What is really basic? What can science contribute to our youth? What are the problems, the trends, the necessary research, and the processes that must be activated as we attempt to design curriculum and instruction for the adults of the twenty-first century?

This issue of *Viewpoints in Teaching and Learning* is far too small to include the comprehensive treatise the topic deserves. The authors recognized this size limitation when planning originated. However, the need was obvious, and the authors' desires to contribute their ideas to the flow of thought needed for the decisions that must be made were compelling. Hence, we proceeded, and now we offer this modest probe of viable ideas as partial fulfillment of the task we must complete in planning the evolutionary science curricula for students who will be our leaders in the next century.

The first two articles define the place of science in the curricula, first as a basic study and then as a holistic study. The next three articles examine the implications that Piaget, Piagetian studies, teaching models, aptitudes, and technology have for improving science instruction and student learning. The last five articles treat some persisting problems and describe some viable solutions: science content selection, science for the handicapped, readability problems, the preservice science preparation of the elementary teacher, and closing the widening gap between research and practice. We hope that you will find this probe interesting and at least somewhat provocative.

Hans O. Andersen, guest editor

Indiana University

Science—A Basic Study

John Rusch

While there is a lack of clarity in the public's mind as to what constitutes basic education, there is demonstrable evidence that basic education should enable persons to solve problems confronted in everyday life. Claims are made that much learning occurs outside formal educational environments, that learning proceeds from concrete physical experience, and that because of the unique cultural and technological milieu of contemporary life, the young are deprived of many concrete experiences to which their predecessors had access. Therefore, schools must provide more concrete learning environments to remediate this experiential deprivation. Basic education is defined as enhancing one's decision making and problem solving abilities by developing intellectual skills and usable knowledge, allowing for problem solving opportunities in a moral and aesthetic context, and allowing the individual to experience the consequences of the problem solving. Science is shown to have unique characteristics that make it a valuable component of a basic education. While stressing the physical world, it develops usable knowledge and intellectual skills, and can provide a good model for rational and moral behavior.

The practice of identifying what is "basic" in education, and attempting to develop a rationale for a particular discipline in light of that definition, has been going on, with varying degrees of success, for generations. Therefore, it is not without precedent but certainly with some risk, that such an attempt be made with respect to science. In the past several years, Gallup (1978) and other takers of the American public's pulse have noted what the media have come to call a "back to basics" movement in the country. There has been much speculation as to the causes for this movement, but it is generally granted that much of the impetus results from a general dissatisfaction with the products of the public education institutions of the country. Graduates of institutions who have difficulty reading, writing, speaking, or performing basic mathematical computations are identified as living proof of the need for schools to re-double their efforts in these areas. Rarely, if ever, is scientific illiteracy brought into such arguments, probably because science education is not viewed as a "basic" in the minds of either the general public or the critics of education.

This paper will offer some outrageous hypotheses for the causes of the existing conditions of poor performance by students. Further, it will attempt to identify what ought to be meant by "basic education" and will provide rationale for the recognition of science in the K-12 curriculum as an integral and a focal area.

Some Outrageous Hypotheses

Hypothesis 1. Students historically have learned more outside of schools than inside.

During the first 150 years of this country's history, Americans came to value those people in the population who exhibited problem-solving skills and technical expertise. The concepts of "Yankee ingenuity" and "good old American know-how" became world-wide trademarks of a people who were subjected to minimal formal education but experienced a lifestyle that seemed to abound in opportunity for the application of human resourcefulness to real world problems. Children growing up in primarily rural and small town environments were acknowledged parts of the family work force and constantly confronted real problems and experienced real mechanisms for problem solving. They truly "learned by doing" and their formal education supplemented, rather than lead, their educational experiences.

Hypothesis 2. All people learn primarily from concrete experience and when they are denied such experiences their learning is impaired.

Piaget and others have long contended that the development of the human intellect is sequential, hierarchical, and invariant (Flavell, 1963). They claim that this development depends on maturation, social interaction, experience (both physical and logical-mathematical), and equilibration (the process of organizing experiences into integrated systems). While this hypothesis may not seem particularly outrageous, educational practice in America generally tends to deny students physical experience with what is to be learned in most instructional settings, and identifies social interaction as an example of misbehavior among students. Further, it understands maturation, solely on the basis of chronological age, and generally ignores the mechanism of equilibration as the basis for developing instructional strategies. The problem of educating American youth is not that the basic skills are insufficiently stressed; rather, it is that these skills are not developed in a meaningful, concrete context.

Hypothesis 3. Societal and sociological change in America have operated in such a way as to progressively deprive students of a quality learning environment to the extent that today's students are more experientially deprived than were their parents or grandparents.

A multitude of changes such as the removal of children from contact with the working world of adults; the growth of cities and suburbs at the expense of rural and small town environments, the segregation of people into discrete age groups and the reduction of opportunities for various age groups to interact; and the development of "pseudo-environments" such as television and the sterile, antiseptic environment of the suburb to which only the solved problems and processed results of a technological society are brought, are but a few examples of the radically different physical and social environment in which young people today grow up. As we become characterized as a nation best known for its ability to consume, so too do our children become more estranged from a knowledge of what the physical world is really like. It is paradoxical that today most Americans live in the midst of a scientific and technological culture which they did not develop and which they do not comprehend. The educational loss to children who cannot experience everyday problems related to food, shelter, and occupational needs cannot be easily documented or measured, but one is forced to conclude that such a loss is real, and that it poses problems, never before experienced, for the effective education of young people.

Obviously, solutions to these problems which have resulted from massive cultural change in America will not come about by an equally massive return to a rural and simplistic lifestyle. Nor will the methods that were appropriate to education in the culture 50 to 100 years ago bear the same results that they did in a previous time.

Hypothesis 4. If schools wish to do as effective a job of educating young people as they did 50 years ago, they must provide remediation for their experientially deprived charges.

Formal education is presently charged with taking the lead in the education of America's youth. The learning environments created by the simpler more elemental lifestyle of 50-100 years ago are gone and will not return. These environments provided the necessary context in which supplemental formal education could be integrated. With this added responsibility, public education must find effective and efficient ways by which the formal learning environment can become enriched with real world experiences and meaningful problem contexts appropriate to the developmental levels of the students. Such changes would bring the school out into the community, would make more use of the outdoors, and would place students in situations where they could attack a variety of problems related to their experiences in these environments. School, in short, would become a laboratory in which students would experience a much broader range of physical and societal phenomena than ever before, under conditions that would allow them to learn how to understand and influence their education.

These hypotheses point to some of the problems facing American education. In addition, they imply a need for changes in instructional practice and curriculum design. Science instruction characteristic of the 1950's and 1960's can make no strong claim in the face of these hypotheses. If it has a place, science instruction must do more than provide prep school training for collegiate courses in science. Also, it must offer more than vocabulary and the result of scientific inquiry. It is in the context of the problems posed by these hypotheses and the need for science instruction appropriate to these problems, that an analysis of the aims of American education and the need for science education as an integral part of it, will be approached.

Basic Education: An Alternative Definition

The almost invariable response to the question of what constitutes basic education is "readin', ritin', and 'rithmetic." The answer is basically a conditioned response and therefore provides insufficient basis for examining the real questions of (a) what is of educational importance and concern to a people who prefer to live in a democratic society and (b) what are the peoples' hopes for the lives and futures of their children. While few would deny that these readin', ritin', 'rithmetic skills are necessary for effective living, there is substantial disagreement on issues related to curriculum and instruction. Gallup and other pollsters have found, when pressing the issue, that the American public equates these skills as essential for problem solving, for chances for employment in good occupations, and generally, for effective citizenship.

Certainly, the original intent of American education was based on the notion that a democratic government could function effectively only provided the population of citizens could make knowledgeable, rational decisions. Furthermore, the more tacit presumptions of a free enterprise economic system demand that people know how to solve problems, as a part of their roles as producers and consumers in the society. Added to these convictions is the concomitant realization that education in a democratic society must encourage rather than impair the concepts of freedom of choice and personal liberty. In other words, effective education in a democracy must be conducted in a way so as to provide a model which is congruent with the principles of democracy. Public education should provide people with options and opportunities to develop their own talents, rather than directing and training people to fill a state-prescribed niche. Indoctrination and authoritarian modes of education are diametrically opposed to the tenets of democracy and are therefore inappropriate.

Even though the argument that education in a democratic society must operate in harmony with the principles of democracy has never been successfully contradicted, public education has often disregarded this primary precept and wandered into practices which could be characterized as the antithesis of democracy in action. Generally, American education is thought of as being a process by which people's options and outlooks are expanded rather than narrowed. While development of occupational training skill and the acquisition of information have developed some claims on the curriculum, they are still viewed, from the perspective of the purposes of education in America, as secondary to the more primary goals of effective problem solving and decision making. While these goals may seem rather vague at first glance, it can be argued that they are at the core of how people live their lives. In a democracy, people are continually forced into the position of having to make decisions and having to solve problems. This is true whether the decisions and solutions involve problems in the physical, political, economic, or interpersonal realms.

However, if "good" decision making and problem solving are the goals of American education, by what criteria can we judge the "goodness"? Certainly the word "good" implies value judgments that may not be related to purely reasoned logical-empirical approach to human problems. Making "good" decisions is a complex of human behaviors. It can be argued that among the components of "good" decisions or solutions to problems are human behaviors that can be identified. Certainly intellectual skills, often identified as intellectual processes, play an important role in problem solving. One must be able to make observations, inferences, formulate and test hypotheses, and control variables when engaged in problem solving or decision making. Such skills, however, cannot be functional out of any real context. It is necessary to have at one's disposal usable knowledge that can then be manipulated by these skills. Usable knowledge, as it is referred to here, has been identified by Ebel (1972) as ". . . an integrated structure of relationships among concepts and propositions. . . .Knowledge is built out of information by thinking" (p. 5). Science educators have long referred to intellectual skills and usable knowledge as "process" and "content" with respect to science.

Knowledge and skill are, however, still insufficient for "good" decision making. Possessing knowledge and having the ability to manipulate it intellectually cannot automatically ensure good problem solving or decision making. Added to this complex must be a more subjective quality that might be identified as wisdom or judgment. This intangible ingredient not only provides an aesthetic and moral dimension to problem solving and decision making, it also makes the activity human. This highly valued but elusive quality grows from human experience. Gaining this perspective does not mean to imply that simply making decisions and solving problems of many types will develop wisdom, although it is likely that the more problems one solves and the more decisions one makes the more likely one is to develop this characteristic. The crucial component of the problem-solving and decision-making process which helps to develop wisdom is the interaction between the problem solver and the solved problem. Living with the consequences of one's decisions is a highly effective and often humbling learning experience. To use the language of systems analysis, the consequences of decision making and problem solving provide the necessary feedback loop that modifies future actions of the problem solver.

This, then, can serve as a definition for basic education in a democratic society: A basic education is one which develops the decision-making and problem-solving abilities of an individual by (a) developing intellectual skills, (b) acquiring usable knowledge, and (c) providing for a wide variety of opportunities in which to solve problems and make decisions in a moral and aesthetic context, while (d) allowing the individual to experience the consequences of the problems solved or the decisions made. This definition, of course, is qualified by the limiting individual factors of physiological, intellectual, social, and moral development of the learner, and the resources and expertise of the teacher. In this context, the three R's are not ignored, but become part of a more comprehensive view of education as it ought to be understood by educators and the public.

Science as a Basic in Education

On what bases can science make a claim as a basic component of public education, given the preceding definition of basic education? What is unique about the sciences that they should become an integral and focal point for the public school curriculum?

First it is necessary to distinguish some characteristics of science which will provide some uniformity of meaning for the word. Science is a human endeavor; it is solely and completely the product of human efforts to construct explanatory models of the physical world. Contrary to popular belief, science is not a description of the world as it is, nor is it merely a series of products or processes which have grown out of people's efforts to solve problems using scientific explanations or models. Science is a way of coming to know. It depends on careful use of intellectual skills. It builds on creative ideas and models that must pass the rigorous tests of being replicable, conforming to observable reality, and not contradicting more basic presumptions which have withstood comparable rigorous tests. As such, science possesses the components of the goals for which American education strives. It relies heavily on intellectual skills; it generates usable knowledge about the physical world; and its practice demands judgment and wisdom, now more than ever before, in a moral and aesthetic context.

While not the sole possessor of usable knowledge or practitioner of intellectual skills, science is unique among the various human endeavors in that it concentrates its efforts on coming to know the physical world which can be observed and experienced by all people. Science also is unique in that it has built into its syntax mechanisms for self-correction and change. The success of science as a means of coming to know about the world can be attributed primarily to its evolutionary self-correcting nature. As such, those who practice science place themselves under certain moral, ethical, and intellectual constraints that make them responsible for the consequences of their efforts.

Of course, science in the K-12 curriculum is not and cannot be the equivalent of science as it is practiced by the researcher of biology, chemistry, physics, or geology. Children and adolescents lack many of the intellectual skills, usable knowledge, and wisdom to conduct science as "little scientists." Yet science has great potential benefit for basic education. Its intimate and total concern with the observable physical world provides a critical component for effective basic education. It relies on physical experience. The physical, real context in which learning science takes place meets a critical need for children and adolescents who lack the ability to deal intellectually with abstractions or propositional thought. At the same time, science has developed precise relationships between the observable world which is experienced, and useful ways of thinking about it and acting on it that depend on abstract thought. While being rooted in concrete experience, science can lead the learner who is developing the capacity for abstract thought, on a clear and direct path into the realm of propositional logic.

Coming to know or develop usable knowledge of the physical world in which one lives does several important things for young people. First, it meets the very human need to be able to explain those phenomena which influence one's life. Second, it gives young people direct feedback as they experience the consequences of their problem solving or decision making. If a student believes that adding mass to a pendulum bob will influence the period of a pendulum, the student can receive direct feedback on that decision from the phenomenon itself. The feedback does not come from an authority. It does not punish the learner. The feedback provides the basis for subsequent decision making and problem solving. When, upon continued investigation, the student finds that the length of the pendulum influences the period, and that it will do so in an invariant and predictable way, the student acquires an important sense of control. The world now becomes a place that can be known by one's own efforts. Continual problem solving experiences that provide learners with feedback which supports the concept that they can control, to some degree at least, the world around them, have great significance for development of self concept and what Rowe (1973) refers to as "fate control" (p. 281). Rowe posits that students will have great difficulty making decisions or solving problems for themselves if they do not believe that they have control over their world or their lives. In this context, science study provides one of the simplest and most effective environments for developing strong self-concepts and a view of the world as being controllable and comprehendable by one's own efforts.

Modern science has several other characteristics that contribute to the legitimacy of its claim as a part of the basic curriculum. Studies by a number of researchers (Kellogg, 1971; Morgan, Rachelson, & Lloyd, 1977; Rowe, 1975) all found that primary grade children who were involved in a modern elementary science curriculum which stressed concrete physical experiences showed significant gains in reading readiness and reading tests. It would appear from these studies that science in the curriculum is supportive of the development of reading skills.

In another study, Harkness (1978) conducted partial linear correlations between the science achievement test scores, the reading scores, and the socioeconomic status (SES) indices of 470 fourth grade students who had been involved in a modern science program. Holding one of the three variables constant for each correlation, he obtained the following: science to reading, .96; reading to SES, .92; science to SES, -.43 (pp. 29-30). The conclusion that success in a modern science curriculum is not linked to socioeconomic status should be an important finding for American education as it attempts to provide equal educational opportunity for all.

Beyond the contributions that science can and does make in developing basic skills, a strong case can be made for the need for scientific literacy in general.

The Need for Scientific Literacy

Broudy, Smith, and Burnett (1964) in their classic discussion of curriculum, distinguish between what they refer to as interpretative knowledge and applicative knowledge. Their contention was that the aim of curricular development in America should be directed at interpretative knowledge; that is, knowledge which would allow people to interpret new problem situations in the light of their existing knowledge. Applicative knowledge in disciplinary areas was of lesser importance for the general curriculum as relatively few people pursue any specific disciplinary area beyond the 12th grade level. It is in the area of interpretative knowledge that one might classify scientific literacy. A scientifically literate individual is one who can read and interpret scientific developments as they might appear in the popular press. Although incapable of actually conducting scientific research, a scientifically literate person would have an appreciation for and an understanding of how such research is conducted, would understand how scientific theories and laws relate to the generation of new knowledge in science, and would possess sufficient knowledge of science principles to comprehend new developments in various areas of science. Such interpretative knowledge in science should be a goal of American education. It would be trite to claim that American life is completely involved with the technological outgrowths of scientific research. Virtually every part of our normal living experiences brings us in contact with the products of scientific inquiry. Science and technology are the major change agents at work today in American culture and probably will continue to be into the 21st century. If, as Whitehead (1929) says, "there is only one subject matter for education and that is Life in all of its manifestations" (p. 10), then science of necessity must play an integral role in education.

One of the main theses of Toffler as he described "future shock" was that scientific and technological advances would proceed in the future at a rate greater than the population at large could relate to them. The consequences of such a development, it can be argued, would create a potentially destructive condition in this country. As knowledge of science and technology becomes more restricted to a relatively small number of people in the population, the majority of people perceive to be, and in fact are, less independent and tend to lose their sense of control of their own lives. To live in a world one cannot comprehend, and over which one has no control, is to be powerless. A collective sense of impotence will inevitably lead either to dependence upon those with power or to revolution, and either option is untenable in a democracy. There already are indications that some trends in this direction could be developing.

The decades of the 1950's and 1960's in which people developed an unwarranted and unrealistic view that science and technology would somehow be a panacea of human existence was followed quickly in the 1970's by an equally inappropriate disillusionment. An uncritical belief in science quickly fell way to suspicion and distrust of science and technology. Federal support for scientific research and development was cut back, counterculture movements began characterizing science and technology as being responsible for societal ills, and a fascination with the occult and other non-rational pursuits flourished.

A quick survey of any bookstore's science section will provide evidence that the interest in pseudo-science has not diminished appreciably. Implausible speculations on topics ranging from UFO's to the Bermuda Triangle, filled with incomplete, misinterpreted, or falsified information is consumed voraciously by a public who would like to believe the unbelievable. The misguided, inhuman scientist still serves as the stereotype villain for Saturday morning children's television, and astrologers greatly outnumber astronomers. A more complete misrepresentation of any area of human endeavor cannot be found in this country. The preceding examples serve as evidence of the need for public scientific literacy. Apart from the intellectual violence done to the American people by such hucksterism, misrepresentation of science is used by vendors of a variety of questionable products from fad diets to home insulation to dupe the public out of millions of dollars each year. Certainly a greater degree of scientific literacy would threaten the success of such endeavors.

However, our society presently faces a number of serious problems of even greater magnitude, and it seems unlikely that solutions which ignore the use of science and technology will be very effective in dealing with them. The depletion of resources, primarily energy resources, will demand serious concern over the next several decades. Control and monitoring of environmental degradation will continue to press for attention. In addition to these, the problems of human health, world food production, overpopulation and their attendant moral and ethical dilemmas will require not only a large cadre of competent scientists but also a scientifically literate public who will collectively make public policy on these issues. The need to combat pseudo-science, the development of public policy issues related to science, the need for scientifically literate consumarism, and the need for an awareness of the limits of the closed system on which we hurtle through space, all demand that a rational understanding of the physical world be a part of the educational experience of all people. As Whitehead (1929) states in *The Aims of Education,*

> Today we maintain ourselves. To-morrow science will have moved forward yet one more step, and there will be no appeal from the judgment which will then be pronounced on the uneducated. (p. 23)

The claim for science as a basic study has validity, but not as the science education of 30 years ago which treated only the results of scientific inquiry in a pedantic and authoritarian manner. The science education of the 1960's also has lost its validity as it directed its efforts at the production of more qualified scientists. The science education that can lay claim as a basic part of the curriculum is that which recognizes the need to integrate itself into the entire curriculum just as science permeates the world in which we live. The notion of science as part of a liberal and humane education which not only gives people usable knowledge and intellectual skills, but which also enables them to comprehend their changing world and respond rationally to it, is the thrust of science's claim in the curriculum. As discrete disciplines, presented in fractured time periods in an overcrowded school day, the teaching of science can make a case which is no stronger than many other disciplines. However, as a nucleus for an integrated curriculum in which students find school difficult to distinguish from real life, science has great power. Science provides the physical experiential context so necessary for the effective learning of young people. It also possesses well-developed mechanisms by which one can come to know for one's self about the world.

While providing the basis for rational inquiry, the spirit in which such inquiry is conducted serves as a model for human behavior which honors honesty, abhors prejudice and bias, and recognizes and rejoices in human creativity while remaining aware of its own limitations. Effective science education should not deny the validity of the aesthetic and non-rational components of human existence, but it has a responsibility for helping young people learn to distinguish among various modes. Science does not provide the only way of coming to know, but it does provide an exceedingly important way. To ignore science in the education of our youth is to cut them off from their heritage, to deprive them of their right to comprehension of the present, and to guarantee the destruction of their future. Although peoples who do not study history may repeat the mistakes of those who preceeded them, they still have the opportunity to study the past even after repeating mistakes. Cultures that ignore the education of their youth in the sciences may not survive to profit from their error.

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Holistic Science: Which Part of the Learner Are You Touching?

Stan Rachelson

This article examines the nature of scientific inquiry with a focus on the process of hypothesis generation. Scientific inquiry is defined as a self-correcting process consisting of two components: hypothesis generation and hypothesis testing. This article takes the position that the *testing* component is receiving adequate emphasis in science classrooms, whereas the *generation* component is not. From this position three directions are explored in order to facilitate a holistic view of the inquiry process. (1) The generation component is defined as possessing the following characteristics: intuitive, imaginary, synthetic, timeless, and metaphoric. These qualities are based on the assumption that the information processing strategies of this component are best performed by the right cerebral hemisphere. (2) The Wallas model of scientific inquiry is presented as a holistic vehicle for celebrating both components of inquiry in science classrooms. (3) Several instructional strategies that encourage the generation component are described.

Readers may recall the story of three blind men who came upon an elephant. Each began touching a different part of this creature's anatomy, and, as expected, their observations varied depending upon which part they explored. Consequently, their inferences about the nature of this mammal were incomplete. The man who examined the trunk, for example, described the elephant as like a snake, whereas the one who explored the leg pronounced it to be like a tree.

This fable has powerful implications for science teaching. It speaks of a fundamental assumption that our knowledge of the world is deeply influenced by our perceptions and interpretations of it. With respect to the teaching of science, if our perceptions and interpretations of science are incomplete, then our instruction will follow suit. By the same token, if our perspective of the learner is unfinished, then so will be the nourishment we provide for his/her growth. To put these ideas in the form of a question: Are our blinders (biases) leading us to touch only a part

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of the discipline of science or, more importantly, only a part of the learner, causing incomplete inferences about the selection and instruction of the content?

Even with a group sharing common professional goals (i.e., science educators), the term "holistic" often conjures up different images. The meaning of the term varies in response to the personal context in which it is applied. In thinking about science education for tomorrow, it seems appropriate to take a holistic view of the concept of "holistic science education." This article explores, therefore, both the nature of science and the mind of the learner.

One begins with a holistic perspective of scientific inquiry, whereby the hypothesis-generating and hypothesis-testing components of this process are seen to form a complementary system. It is suggested that in the teaching of science there is presently an overemphasis on the testing component to the exclusion of the generation component. From this point, a holistic view of the mind of the learner is presented, whereby the thinking characteristics of the left and right cerebral hemispheres are seen to form a complementary system. It is suggested that the operations of testing hypotheses is best performed by the left hemisphere, whereas the operations inherent in generating new hypotheses is right hemispheric in nature.

To create science educational environments that present a holistic view of the inquiry process, and therefore engage science students to use their whole minds, the Wallas model of inquiry is presented as a guideline.

Scientific Inquiry

Scientific inquiry is a problem-solving process that is self-correcting and revisionary in nature. This process has two components: hypothesis generation and hypothesis testing (Martin, 1972). A complementary relationship exists between the process of generating a hypothesis and the process of testing it. Neither operation can be subsumed by the other, nor can either be considered as independent of the other (Blackburn, 1971). Although each of these components shares the common ground of referring to the same reality, each possesses distinct characteristics. A complete, holistic model of scientific inquiry must include descriptions of both the mental acts inherent in hypothesis generation and hypothesis testing.

Hypothesis generation consists of those mental activities that yield a tentative explanation of a problematic situation. There are, however, an infinite number of hypotheses that may provide an explanation for any given problem. The chief function of the generation component of scientific inquiry is to provide the investigator with only plausible hypotheses (Peirce, 1935). This identifying of possible hypotheses is a selection process of extreme importance to the scientific enterprise. Since a scientist may spend a lifetime engaged in testing only one hypothesis, it is necessary to examine one that is feasible and closely related to his/her problem. As Medawar (1969) writes, "the hypothesis that enters our minds will as a rule be plausible and not, as in theory could be, idiotic. But this implies some internal censorship which restricts hypotheses to those that are not absurd" (p. 53). The "internal censorship" referred to by Medawar can be viewed as the operation by which man contacts his intuition. Intuitive thinking during hypothesis generation serves as a conduit between man and nature, and its acts yield hypotheses that are testable with respect to the natural phenomenon in question (Poincaré, 1952; Peirce, 1935).

The *hypothesis testing* component of scientific inquiry consists of those mental activities that expose a hypothesis to external experience, usually by experimentation. The goal of this component is to confirm or refute the validity of a hypothesis, and is public as opposed to the private nature of hypothesis generation (Medawar, 1969). An investigator makes his/her hypothesis public to others through the use of operational definitions, and it is tested in a manner which prevents subjective deception with regard to its intuitive conception.

Hempel and Oppenheim (1948) depict this preventive manner as operating with firm rules which ensure uniformity and confidence. A hypothesis exposed to criticism is analyzed by the combined use of deductive and inductive inferences. First, an observable consequence or prediction is deductively formulated. This approach guarantees that if the hypothesis is true, then so will be the prediction which is derived from it. Next, experimental controls are used to isolate the prediction to determine its correspondence with reality. If the prediction is confirmed, as defined by the testing conditions, then the hypothesis is confirmed (Hanson, 1958).

The Practice of Science

Curriculum efforts of the sixties and seventies have been directed toward materials and strategies that facilitate the understanding of scientific inquiry (Klopfer, 1969). This energy can be interpreted as evidence of a significant change in the evolution of science teaching—a shift away from what is primarily a *factual or conceptual emphasis*. Dressel, Burmester, Mason, and Nelson (1960) reviewed articles that examined instructional efforts designed to encourage the inquiry process. They reported that "research studies indicated that the acquisition of scientific methods and attitudes is facilitated by instruction" (p. 47). Given that the process of scientific inquiry can be effectively taught to students, it is necessary to examine whether *both* the generation and testing components of this process are being emphasized in science classrooms.

A review by this author of several hundred research articles in science teaching reveals that an *incomplete* picture of scientific inquiry is being presented to students. The vast majority of the articles reviewed examined hypothesis testing operations, such as the students ability to form deductive consequences and to identify and control variables. Only a few articles examined the operations inherent in hypothesis generation. The underlying assumption for examining researches in science education is that the context of these studies is science classrooms; therefore, research evidence, for the most part, reflects or extends current practices in the teaching of science. (This review included an examination of articles in *The Journal of Research in Science Teaching*, Vols. 1-12, and articles in *Science Education*, Vols. 44-60.)

In addition to inferences made from researches in science education, supporting evidence for the overemphasis of the hypothesis testing component comes from individuals who have theoretized about the teaching of science. For Rogers (1961), science education is transmitting an incomplete picture of scientific inquiry. The creative phase of formulating hypotheses is taken for granted, is underemphasized, and tends to be forgotten. A view of scientific inquiry developed for students is characterized by the verification of a hypothesis *presented* to them. The vast structure of "operationalism, logical positivism, research design, and tests of significance" has become self-serving instead of existing "as servants in the attempt to check the subjective feelings or hunch or hypothesis of a person with objective facts" (p. 28).

Feyerabend (1975) agrees with Rogers' assessment. He criticizes science education of fostering a one-sided definition of scientific inquiry, and believes that many science educators are attempting to inhibit intuition and to restrain imagination. This disposition is a serious state of affairs, and Feyerabend questions "whether science can advance without strong interaction between the separated domains of justification and discovery" (p. 166).

One possible cause for this disposition rests in the historical and philosophical foundations of the nature of science. Historically, science in its developmental stages became associated with the sequence involved in hypothesis testing. The establishment of science as a legitimate mode of knowing required a reactionary break with the religious enterprise. The trial of Galileo is an excellent example. Intuitive inspiration, a necessary element in the generation of hypotheses, was viewed as too closely related to religious ways of knowing and these acts became secondary to the operations of induction and deduction. Two philosophical schools of thought have propelled this reactionary view of scientific inquiry. They are "inductivism" and "hypothetic-deductivism."

Elements from each of these philosophies can be traced to current practices in science classrooms. It is viewed, however, that the hypothetic-deductive view seems to have received the most emphasis by curriculum developers. This philosophy, once championed by the "Vienna Circle" of logical positivists, is advocated by several philosophers of science, including Hempel and Popper. This model of scientific inquiry is devoted to the reasons for accepting or refuting a hypothesis after it is well formulated. It is not concerned with the generation of a hypothesis as illustrated by Popper (1959):

> The initial stage, the act of conceiving or inventing a theory, seems to me neither to call for logical analysis nor to be susceptible of it. The question of how it happens that a new idea occurs to a man may be of interest to empirical psychology, but is irrelevant to the logical analysis of scientific knowledge. (p. 33)

Certainly, no major criticism can be placed on Popper's attempt to define his system by excluding the acts of hypothesis generation. Furthermore, many empirical psychologists—including Torrance, Guilford and Taylor—have spent considerable effort in studying the generative process. As stated earlier, however, a serious state of affairs exists when science educators adopt a philosophical underpinning that separates the component justification from that of discovery.

In search for philosophic underpinnings that are more holistic with respect to the inquiry process, science educators can find more balanced viewpoints in the works of philosophers, including Polanyi (1964), Peirce (1935), Medawar (1969), Poincairé (1952), Bronowski (1965), Maslow (1966), and Hanson (1958). Medawar (1969), for example, proposes that the lack of emphasis placed on the hypothesis generating component by the hypothetic-deductive system to be its chief weakness. He states that "the major defect in the hypothetic-deductive scheme...is its disavowal of any competence to speak about the generative act in scientific inquiry. . . .The objection is all the more grave because an imaginative or inspirational process enters into all scientific reasoning" (p. 55).

Science educators of today and tomorrow can now reflect and teach a discipline that not only is firmly established, but also is one on which the survival of man is intimately dependent. It is now possible to accept and *act* on the fact that scientific inquiry has two equally crucial parts. Since hypothesis testing is *already* assumed to be a part, this acknowledgement must take the form of explicating the hypothesis generating component to the point where instructional strategies can be introduced with regularity in science classrooms.

Holism and the Mind

Inquiries about the world are obviously a function of the thinking processes of the investigator. It is important, therefore, to examine these processes in an effort to define the thinking characteristics of the generation component. From this point we are in a position to provide our students with a holistic model of scientific inquiry. This section explores the relationship between the two components of inquiry and the two complementary sets of thinking processes of the human cerebrum.

The cerebrum is a structure of the brain which is unique to vertebrates. It is the most recent neurophysiological structure to evolve, and its functions are superimposed on earlier structures such as the cerebellum, pons and medulla. The cerebrum in man processes higher order sensory information, therefore equips human beings with the capacity for language, memory, imagery, calculation, intuition and reflective thought. Separation of this structure into two hemispheres is an even more recent evolutionary development, occurring only in the more complex vertebrates. Furthermore, studies with primates in this area demonstrate that their cerebrum, while separated into two hemispheres, is *not* differentiated along an information processing dimension (Gazzaniga, 1970). In other words, each hemisphere thinks identically, just as, each eye, lung, and kidney performs identical functions. The human cerebrum, however, is alone at this level of sophistication. Each cerebral hemisphere processes its information in a very different manner.

Knowledge of this truly revolutionary discovery has led to researches directed toward *identifying* the specific thinking characteristics of the left and right hemispheres. Table 1 is a summary of this research evidence, which has brilliantly identified these characteristics (Sperry, Gazzaniga, & Bogen, 1969; Levy, 1974; Kimura, 1973).

Table 1

Information Processing Strategies of the Cerebral Hemispheres

Left Hemisphere	Right Hemisphere
Analytical (Sequential)	Synthetic (Holistic)
Rational (Logical)	Intuitive (Inventive)
Time	Space (Timelessness)
Verbal	Images
Linear	Metaphorical

When examining the different strategies utilized by each hemisphere, it is discovered that the operations of the left and right hemispheres *complement* each other. Levy (1974) believes that it is as if one hemisphere simply does not process information that can be more adequately handled by the other. During a reading task, for example, the left hemisphere is superior to the right in its performance. Reading is a skill that is verbal, analytical, linear, and rational in nature. During a visual-spatial task, such as perceiving three-dimensional shapes, the right hemisphere is superior to the left in performance, since this task requires synthetic, spatial and imaginary thinking processes.

Present data indicate that the left and right cerebral hemispheres share *equally* important responsibilities for processing information. It is now believed that the human brain operates through the integration of two complementary modes of consciousness. The mechanisms in which the hemispheres interact with each other is not as yet clearly understood. Ornstein (1972) posits that in most intellectual activities, such as scientific inquiry, the mind simply alternates between the right and left hemisphere selecting the appropriate one to function and inhibiting the other.

In our search for a relationship between this neurophysiological empirical evidence and the teaching of science, Samples (1975, 1976) has provided the creative leadership. He attributes our current overemphasis on the hypothesis testing component in science classrooms as a reflection of a one-sided *attitude* toward what he refers to as "left-hemispherical thinking." These are the processes of rationality, analysis, and time and, correspondingly, are the mental operations inherent in deductive and inductive thought. Samples goes further to relate this condition to a philosophical (hypothetic-deductive) view of scientific inquiry, which he describes as a totally logical and analytical enterprise. This position is translated to science classrooms at the expense of the mental operations of the right hemisphere. These are the processes of synthesis, metaphor intuition, timelessness, and imagination, and correspondingly, are the qualities of the hypothesis generating component to scientific inquiry.

This brings us to the crux of this article. If science educators at all levels of instruction are presenting a model of scientific inquiry to students in a manner that emphasizes the hypothesis testing component to the exclusion of its complementary partner, then those educators are touching only a part of their students' minds. A holistic model of scientific inquiry is balanced, and celebrates *both* of the crucial components of the inquiry process, thereby involves the students in development and use of thinking strategies of both cerebral hemispheres.

It is now necessary to guide the direction of this article in three related directions. First is a definition of the characteristics of hypothesis generation. Second is the framing of these characteristics within a holistic model of scientific inquiry that is applicable to science classrooms. Last are brief descriptions of instructional strategies that are consistent with both the qualities of hypothesis generation and the Wallas Model of scientific inquiry.

Characteristics of Hypothesis Generation

With the identification of the complementary thinking characteristics of the cerebral hemispheres, it is now possible to operationally define the characteristics of the hypothesis generating component in forms that can be translated to science classrooms. There are five characteristics of the generation component: intuitiveness, synthesis, imagery, metaphoricalness, and timelessness (Rachelson, 1977). As alluded to earlier the underlying assumption for this position is that the operations of *testing* hypotheses are best performed by the information processing strategies of the left cerebral hemisphere, whereas the operations inherent in *generating* hypotheses are best performed by the right hemisphere.

Previous efforts in defining these characteristics have occurred through an analysis of case-history reports of scientific investigations. Fertile examples of this type of data include the accounts of Kekule, Wallace, and Poincaire. Problems arose from this data, however, which may have limited the formulation of instructional strategies that facilitate the generation component. Because the right hemisphere lacks a developed verbal capability (see Table 1), and processes its information in images, definitions and descriptions of hypothesis generation by these and other investigators were often *unspecific*. For example, Poincaire (1952) distinguished between the testing and generation components as the working of the "conscious ego" and the "subliminal ego" respectively. Other phrases such as: "something brought to recollection" (intuitiveness), "ideas I first heard about years ago" (timelessness), "an image from a dream" (imagery) and "suddenly I could see the whole of things" (synthesis) leave the science educator with little to go on in attempting to create a model of scientific inquiry that is consistent with the practice of science.

To frame the five characteristics of hypothesis generation within the science classroom so that both components of the inquiry process are valued, the Wallas model of scientific inquiry is used as our vehicle. In creating his model, Wallas (1927) relied on many descriptions of mathematical and scientific investigations. In addition, this model is also consistent with the two-component definition of scientific inquiry, and is congruent with the complementary nature of the thinking processes of the cerebrum.

The Wallas Model

The Wallas Model of scientific inquiry moves through four stages: preparation, incubation, illumination, and verification. The *preparation* stage begins after the scientist or student is confronted with a problematic situation. It is this situation that creates the cognitive dissonance and subsequent motivation to power the inquiry process (Festinger, 1962). This stage is a "hard, conscious, systematic and fruitless analysis of the problem" (Wallas, 1927, p. 81). The mental processes of deduction and induction operate during this stage.

The *incubation* stage is a voluntary abstention from conscious thought about the problem. Conscious thought is defined here as a purposeful, intentional attempt to solve a problem. In addition Wallas implies that "conscious thought" entails those mental acts that occur during the preparation and verification stages. The goal of the incubation stage is to search for a successful solution to the problem. This process involves the sifting and reshuffling of the concepts and ideas the investigator possesses in search for what Koestler (1964) describes as a *successful* frame of reference. This type of thinking can occur in a variety of formats such as long walks, sleepless nights, relaxed states of mind, and day or night dreaming. The mental processes of intuition, imagination, metaphor, and synthesis guide the search for a successful frame of reference. Since it is during the incubation stage where hypothetical solutions about the problem are formulated, this stage can also be called the *hypothesis generation* component of scientific inquiry.

The *illumination* stage is described by Wallas as very short and highly energetic. Basically this stage represents the formulation of a new hypothesis through the combination of information gained in preparation and knowledge gained through incubatory thought about the problem. Case-study evidence indicates that the investigator is oftentimes overcome with a flood of emotion, which stops his/her activity and causes immediate reflection. Koestler (1964) and Pearce (1973) have referred to this stage as the "Eureka experience." Pearce states that "In every recorded case of *Eureka!* illumination, the final breakthrough of the postulate occurs when the logical processes have been momentarily suspended. . ." (1973, p. 72).

The *verification* stage closely resembles the preparation stage, since the same rules of logical inference apply to both. Predictions are deduced from the plausible hypothesis generated during incubation, and experimental conditions are induced to test them. Poincaire (1952) calls the verification stage a "second period of conscious work which follows the inspiration, and in which the results of the inspiration are verified and consequences are deduced" (p. 63). From our definition of scientific inquiry, it is clear that the verification stage is the *hypothesis testing* component.

When superimposing the neurophysiological researches about the complementary functioning of the cerebral hemispheres onto the Wallas model, a significant correspondence emerges. The left and right hemispheres have *both* assumed the role of orchestra leader in guiding the inquiry process. The left for the preparation and verification stages, and the right for the incubative stages. Both hemispheres co-lead the brief climactic illumination stage. Table 2 depicts these relationships.

At this point a brief summary is warranted. Thus far, a two-component definition of scientific inquiry has been presented. In addition, information about the complementary functions of the cerebral hemispheres has been related to this definition. A perspective of science teaching that is presently overemphasizing the left hemispheric operations of hypothesis testing indicates a need for an instructional model of scientific inquiry which includes the balancing holistic influence of right hemispheric operations of the generation component. The Wallas model of scientific inquiry is such a model. In regard to this model, it can be said that the curricular efforts of the sixties and seventies in science education have done an excellent job of creating activity-oriented classroom environments consistent with the preparation and verification stages. In addition, considerable energies by Richard Suchman (1961) and others have been directed toward creating problematic (dissonance causing) situations within the learner. What is needed to complete the model is the introduction of instructional strategies that facilitate incubatory thought within the learner. The rest of the article, therefore, includes some teaching strategies which facilitate this thinking. Since illumination is dependent and follows from incubatory thought, facilitation of incubation will be considered as facilitating the illumination stage as well.

Before exploring the characteristics of incubatory thought for application to science teaching, it is important to mention two possible problems which may arise in translating the incubation process of the research scientist to that of a student in a classroom. As mentioned, this thinking is a voluntary abstention from conscious thought about a problem which can occur in a variety of formats. The term "voluntary" presents no difficulty in translation since it represents an intentional act that can be included in an instructional environment. The phrase "a variety of formats" also presents little problem since a variety of instructional strategies are at our disposal. But how to illicit thought about the problem which is not *conscious, rational or logical* is of chief concern to the science educator. In addition, the scientist is relatively unstructured with respect to time for incubation, whereas the student operates within a time-bound environment. The following strategies are designed to alleviate, but not completely eliminate, both of these problems. They are each consistent with the characteristic right hemispheric thinking, and are also designed to *expedite* this thought so that incubation can be accomplished with success in science classrooms.

It must be kept in mind that the instructor is the time manager in a classroom and serves as the leader in making decisions about the use of incubatory techniques. It may be necessary to allow incubation to extend for several class periods during which the students may be engaging in preparatory or verificatory thought about *other* problems. Also, it is important to note that more than one incubatory strategy can be applied with regard to the same problem. It is logical to assume that as the students become familiar with the Wallas model (whether implicitly or explicitly) they can become the best managers of the incubation periods. Obviously, there is no guarantee of illuminatory success for each student for each problematic situation. There is little or no probability of successful hypothesis

Table 2
A Description of Scientific Inquiry

Stages of Wallas Model		Cerebral Hemisphere in Operation	Component of Scientific Inquiry
	The investigator is confronted with a problematic situation		Creation of cognitive dissonance and therefore motivational energy for inquiry
PREPARATION	Through deduction and induction, the investigator engages in a fruitless analysis within one frame of reference.	Left	
INCUBATION	Guided by intuition, the investigator searches and selects from among other frames of reference.	Right	HYPOTHESIS GENERATION
ILLUMINATION	Preparatory frame combines with the Incubatory frame to produce plausible hypothesis.	Right-Left	
VERIFICATION	Through deduction and induction, the hypothesis is analyzed and either confirmed or disconfirmed, or revised.	Left	HYPOTHESIS TESTING

generating experiences, however, without the allowance and encouragement of incubatory thought.

Instructional Strategies for Hypothesis Generation

Because of the scope of this article, only a brief description of three instructional strategies consistent with the qualities of hypothesis generation are presented. These strategies—the incubation journal, guided imagery, and synectics—are designed for science teaching at all levels (K-College), and need only be modified by the teacher for the developmental level of his/her students.

The Incubation Journal. Most science classrooms encourage the keeping of a science log. Oftentimes, however, these logs become reserved for hypothesis testing information such as recording temperatures, distances, etc. The purpose of the incubation journal is to extend the science log by encouraging students to record their incubatory thoughts about the problem (Parnes, 1962). Since students may, and often do, record incubatory thoughts outside of the classroom, it is important for the teacher to talk about the characteristics of incubatory thought. This information will create the expectancy for incubatory thought, and will greatly enhance the probability for this thinking to occur. The incubation journal can satisfy each characteristic of hypothesis generative thought, but it is strongest with respect to the timeless nature of this kind of thought.

Guided Imagery. The guided imagery instructional strategy is designed to facilitate the imagery processes of the student in *purposeful* directions. During inquiries in science teaching, it is a method that places the learner in a state of incubatory thought. Since the right hemisphere processes its information in images, this strategy illicits this kind of thinking. The guided imagery technique also satisfies the other characteristics of incubatory, right-hemispheric, generative thought. Research evidence (Horowitz, 1970; Gordon, 1972) indicates that a person in an imaginary state also perceives information in a timeless, intuitive, synthetic, and metaphorical manner. Whenever a problematic situation confronts the student within the classroom, it can be transformed into a guided imagery experience designed to facilitate incubatory thought (Rachelson, 1977).

Synectics. The concept of synectics (from the Greek) means joining together of different and apparently irrelevant elements. The synectics approach is used to enhance the probability of success in generating possible solutions about problematic situations. This approach contains two essential elements: (a) making the strange familiar, and (b) making the familiar strange (Gordon, 1961). Basically, this method is designed to elicit solutions through metaphorical thinking. Case study reports of scientific investigations are full of examples of metaphorical connection. Some quotations that come to mind are Kekule's "The configuration of the organic carbon molecule is like a ring of serpents biting their tails"; Harvey's "The heart is like a pump"; and Darwin's "The origin of the species is likened to Malthus' principles of human population." The synectics technique can be used in science classrooms, and can be closely accompanied by a guided imagery preceeding it, followed by discussion and recordings in the incubation journal.

A current perspective of the teaching of science indicates a shift from an emphasis on factual outcomes to an emphasis on the understanding of the two component process of scientific inquiry. Furthermore, this shift has begun with a focus on the testing component of inquiry. A view of science education for tomorrow incorporates an emphasis on the operations of the generation component in a search for a holistic, balanced presentation of the inquiry process to sudents. Polanyi (1964) would view this holistic addition of hypothesis generative strategies as an attempt to "re-equip man with the faculties which centuries of critical thought have taught him to distrust" (p. 38).

It is possible for science educators, at all levels of instruction, to translate this holistic perspective to the classroom by adopting a model of inquiry that celebrates both components of the process. In addition, this effort can become more complete by the introduction of instructional strategies consistent with the characteristics of the generation component. It is through this effort that our blinders will be removed so that we touch the whole learner.

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Piagetian Research as Applied to Teaching Science to Secondary and College Students

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In the past 10 years, numerous studies relating to Piaget's formal operational stage have been reported in the literature. These studies can be categorized as classification studies, instrument validation, maturation and history studies, training studies, and classroom applications. Early research concerning applications of Piaget's work was concerned mainly with determining the level of cognitive development of students enrolled in high school and college science courses, and in training students to perform particular Piagetian tasks. It now focuses on the development of valid and reliable paper and pencil tests for determining students' cognitive level of development and on effective classroom procedures for helping concrete operational students both improve achievement and become more formal in their thinking.

In the past 15 years science educators have been exploring the implications of Piaget's theory for science instruction. Mallinson (1977) in his review of the science education research for 1975 stated:

> Education is replete with the ascendance and decendance of messiahs who capture the fancy of those who teach. The Twentieth Century has had its share; for example, Thorndike and Connectionism, Dewey and Learning by Doing, and Bloom and his Taxonomy of Educational Objectives. There have been, of course, many others but the current star is Piaget. (p. 10)

The number of articles based on Piagetian theory that appeared in 1977 in science education research journals exceeded the number published in the previous four-year period. Does this proliferation of research reflect the science educators' hope that Piagetian theory has instructional implications that will help students learn science better? What has been the thrust of this research? Has this hope been fulfilled? These questions will be explored in this paper.

In the past five years major emphasis on Piagetian research has shifted from the preoperational and concrete operational aspects of the model to formal operations. The research in this area can be divided into five categories: classification studies, instrument validation, maturation and history studies, training studies, and classroom application.

Classification Studies

Most of the research on formal operations in the early 1970's focused on measuring the developmental stages of high school and college students, and subsequently on classifying them as concrete or formal operational. Large numbers of studies were conducted in this area because science educators/college science instructors, who assumed that students enrolled in high school and college science courses could reason abstractly, were astonished to find considerable numbers of students operating at the concrete level. Studies of this nature continue today by instructors who confirm earlier observations (Kelly & Kelly, 1978). Chiappetta (1976) aptly reviewed studies assessing adolescents' developmental stages that used at least three Piagetian task interviews. He concluded from examining 10 studies that more than 85% of the adolescent and young adult population of the United States does not appear to be at the formal operational level of intellectual development.

Although all science educators may not agree with the percentage Chiappetta indicates, it seems quite conclusive that a large segment of the population does not think formally. This suggests that science educators not dwell on replicating studies in this area but direct their efforts toward how to teach science at the high school and college levels to students who do not think formally.

One of the difficulties that researchers found in determining the developmental level of students was that assessment involved interviewing each individual student. This procedure not only was time consuming, which in effect limited the sample size, but also was fraught with the typical problems associated with the clinical method, e.g., training the interviewers, establishing high reliability, and validity. In order to avoid these problems researchers saw the need to develop non-interview Piagetian-like tests.

Instrument Validation

The major aim of researchers who have developed tests to assess the developmental level of adolscents is to produce a test that is valid, reliable, efficient, and practical. Tests usually are either entirely paper-and-pencil types or paper-and-pencil combined with demonstrations (either live or videotaped) by the instructor. The production of a test meeting the above requirements is a formidable undertaking because of the difficulties involved in establishing the validity and reliability. To establish validity the researcher must compare students' performances on the written test with their performance during interviews. It is not only time consuming to interview large numbers of students but one also must account for carry-over of a learning effect from the written test to the interview or vice versa. If the researcher waits for a long period of time to elapse between tests to eliminate any learning effects he or she then must cope with maturation effects.

Many researchers have written Piagetian-like tests. Some of these tests have a high degree of logical equivalence to Piagetian interview tasks in that the researcher demonstrates or has diagrams of Piagetian tasks followed by a series of questions. These questions use a free response or multiple choice format. Tests that have high logical equivalence have been produced by Gray (1973), Raven (1973), Lawson (1978), Renner (1977), Tisher (1971), and Staver (1978).

Other test developers have produced tests with less logical equivalence. Several have written tests that are based on the same mental schema that Piaget used, such as proportional reasoning, but they do not use Piagetian tasks exclusively as the basis of the test items. Tests created by DeLacy (1967), Bart (1970), Burney (1974), Nelson (1969), and Shayer and Wharry (1974) fall into this category.

Another group of tests have been produced that appear to measure students' ability to think abstractly and logically but that otherwise have little resemblance to the tasks used by Piaget and Inhelder. These have been developed by Case and Collinson (1962), Keats (1955), Longeot (1964), and Shapiro and O'Brien (1970).

From the above, it is evident that much tedious work has been done in test production. Certainly tests in the first category (e.g., Gray, 1973; Raven, 1973; Renner, 1977) are approaching the equivalent of administering a clinical interview, yet are more efficient.

Is the work in this area complete? If science educators are looking for a paper-and-pencil test that is 100% equivalent to the Piagetian interview, then the obvious answer is "no." The probability that this equality will ever be reached is infinitely small. If from the instruments that now exist, differences in mental development of adolescents can be measured with a fair degree of certitude, then perhaps more effort should be placed in using the instruments in experimental studies than in developing even more instruments. It is unlikely anyway that all researchers will use the same instruments to classify students or to measure changes in their development. There will always be a need for interpretation and explanation of results.

Maturation and History Studies

According to Piagetian theory, a level of maturation and sufficient experience requiring logical thinking are necessary conditions for students to progress from the concrete to the formal level of development (Inhelder & Piaget, 1958). Because secondary school and university students have probably attained the necessary maturational level and the school environment should have exposed them to numerous concrete and formal tasks, one might expect to see changes in level due to school attendance.

Several investigators have examined changes in developmental level over periods of time of one year or more. Karplus and Karplus (1972) found that at least one-third of the students in their sample did not change substages over a two-year period on a proportional reasoning test. In addition they found that when the school experience facilitated students' mental development, high ability students benefited more than low ability students.

Studies by Schwebel (1972) and Kolodiy (1975) using college students have shown similar results. Schwebel measured changes in developmental stages of college freshmen over a one-year period. Results of this study indicated no change on students' cognitive development. Kolodiy's sample was composed of 20 high school students enrolled in a biology course, 25 college freshmen enrolled in physics and mathematics courses for science and engineering majors, and 25 college seniors majoring in science. He found that there was a greater number of "upper concrete students" in the high school group than in the college freshman group, and a substantially larger number of "upper formal" students in the college senior group than in the college freshman group. He also found that college freshmen who were concrete thinkers dropped out of science courses more frequently than did formal thinkers, thus accounting for the large number of formal thinkers at the senior level.

Results of the above studies seem to indicate that school experience does not directly aid students in attaining the formal level of cognitive development. Can cognitive growth be promoted more directly? Some science educators have thought so. This assumption has resulted in a number of studies in which the investigators attempted to train students on certain Piagetian tasks.

Training Studies

Many training studies have appeared in the literature since 1971. They can be classified into two distinct areas: (a) studies in which students were trained to give correct responses on specific Piagetian tasks, and (b) studies in which emphasis was placed on a particular mental operation (i.e., proportional reasoning, controlling variables etc.). Educators are interested in training students to attain the mental schema characteristic of formal operations because success in science has been shown to depend on acquisition of the schema (Kelly & Kelly, 1978).

In the first category are studies by Bass and Montague (1972) who used ninth-grade students and trained them on the balance problem and the cart-on-an-inclined-plane problem, Brainerd and Allen (1971) who attempted to teach conservation of density to 10 and 11-year-old students, and Siegler, Liebert, and Liebert (1973) who tried to enhance the achievement of fifth-grade students on the pendulum tasks. All of these investigations met with some success indicating that instructional procedures can be developed to teach students delimited Piagetian tasks, even when students are at the lower age limit for the attainment of formal thought. What was not determined by the studies was whether the mastery of tasks was permanent or transitory. This lack of retention data diminishes somewhat the usefulness of these results. In addition, these studies tell us nothing about the students' ability to generalize from the tasks learned to others similar in nature.

The second category of studies differs from the first in that investigators trained students in particular mental operations rather than on specific tasks. Of all of the mental operations, the controlling of variables has been the one on which most research has been done. Lawson, Blake, and Nordland (1975); Case and Fry (1973); Bredderman (1973); and Wollman and Lawson (1975) have explored this area.

All of these investigators found that it is possible to teach students to control variables in certain situations. Bredderman found that there was no retention of the skill, however, when he retested students (fifth and sixth grades) one month later. Lawson, Blake, and Nordland (1975) as well as Case and Fry (1973) trained secondary students. The former researchers found that students were unable to transfer the skill from one task to another and neither group tested students' retention. Lawson and Wollman in training fifth- and seventh-grade students found that particularly with seventh graders there was some transfer of the skill to novel situations.

Training in other mental operations also has met with some limited success. Hammond and Raven (1973) trained students on compensatory operations. They found that eighth-grade students performed significantly better than sixth-grade students on the tasks. Lawson and Wollman (1975) found that seventh-grade students can be successfully taught to solve problems involving proportionality. Delayed post-test results indicated that the training effects were lasting. Nous and Raven (1973) selected correlative thinking as the target of their training efforts. They studied the effects of a set of structured training exercises designed for fifth-, seventh-, and ninth-grade students. They concluded from their study that only the ninth-grade students profited from the training.

From the training studies reviewed above, two conclusions can be drawn. First, it is possible to train students on certain mental operations although it is still questionable whether the skill is transferrable and long lasting. Second, training is more successful if it is given to more mature students (eighth- and ninth-graders) than to younger students. These results may be due to the absence of equilibration and self-regulation in younger students. Certainly the training does not harm the students and in fact may provide them the necessary experiences that at some later time will help them to acquire more easily the mental schema.

Some researchers and science instructors have believed that students need a large number of experiences extended over a long period of time to acquire mental schema characteristic of the formal operational stage. Others recognize that their college and high school science classes have a considerable number of students who do not think on the formal level. The following section will discuss methods and procedures that have been used in high school and college classrooms to aid formal development and/or facilitate science achievement.

Classroom Applications

Two major approaches have been used in science classrooms to aid the concrete thinker and, it is hoped, to promote their cognitive development. These approcahes are (a) making instruction more concrete and (b) using inquiry techniques.

Several science educators have attempted to make science instruction more concrete. Goodstein and Howe (1978), Drugge and Kass (1978), and Gabel (1978) have examined the effects of using models with chemistry students.

Goodstein and Howe found that the use of concrete physical models did not aid concrete operational students but did aid advanced formal operational students. In a study recently completed by the author, the use over the entire school year of physical molecular models aided both concrete and formal students in chemistry achievement. Similar results have been reported by Sheehan (1970) in mathematics achievement. Drugge and Kass used both mental models (analogies) and physical models in a study examining the effect of both of these models on chemistry achievement. They found that mental models were not helpful but that one of the three physical analogies they used was effective.

The above studies lead one to conclude that certain physical models are useful in science instruction for both concrete and formal operational students. Goodstein and Howes' failure to affirm the usefulness of models as an instructional aid may have been due to insensitivity of their instruments, the type of models used, or to students having too brief an encounter with a particular type of model.

The three studies briefly discussed above compared achievement of students who used concrete aids versus those who did not. Other science educators have adopted concrete methods in their classrooms without attempting to formally test their effectiveness. Grotz (1977) and Katz (1977) report increased student interest and lower failure rates in courses taught using concrete aids.

The other approach that has been used in the science classroom to facilitate the learning of science by concrete operational students and also to promote their formal reasoning has been an inquiry method endorsed by AESOP (1976). The publication of a set of books and development of a series of workshops throughout the country explaining each of three phases used in this approach (exploration, invention, and discovery) as applied to teaching physics, chemistry, biology, earth, and general science undoubtedly has influenced the number of science educators using this method. Studies using this approach with college students have been reported by McKinnon and Renner (1971), Renner and Paske (1977), Gerson and Primrose (1977), and Pavelich and Abraham (1977) and with high school students by Smith and Van Egeren (1977).

All of the studies compared achievement in the course and on standardized tests and/or changes in developmental stages of students using inquiry, as compared with a control group. Of three studies (Gerson & Primrose, 1977; Pavelich & Abraham, 1977; and Renner & Paske, 1977) those by Gerson and Primrose and by Renner and Paske reported a positive effect on achievement; of four studies (McKinnon & Renner, 1971; Pavelich and Abraham, 1977; Renner & Paske, 1977; and Smith & Van Egeren, 1977), those by McKinnon and Renner, Renner and Paske, and Smith and Van Egeren reported greater changes in developmental level with students in the experimental group. These studies seem to indicate that the method is successful. Closer examination of the studies indicates, however, that one should make this generalization with caution because of the research methods used. In some cases volunteers participated, randomization was limited, and sample size was small. In addition, the enthusiasm of the instructor may have had a considerable effect on student achievement in the course. Before placing too much hope in this method, more research using carefully controlled methods is in order.

Conclusion

This paper has reviewed some of the Piagetian research studies on the formal operational stage that have been reported during the past decade. Emphasis in the period has shifted from studies that determined the developmental level of adolescents and focused on training studies to research involved with instrument production and validation, and classroom practices. From the research one can conlude that many students in high school and college science classrooms operate on a concrete level and that adequate instruments have been developed for more Piagetian studies. It is also becoming increasingly evident that Piagetian theory does have important implications for science instruction. The use of concrete physical models and the incorporation of an inquiry laboratory format are promising practices that appear to be beneficial to both concrete and formal students on the high school and college levels. Whether or not these practices simply make students more attentive to what is presented to them and which subsequently results in their increased achievement is yet unknown. More research in the application of Piagetian theory to science achievement is needed.

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The Use of Learner Aptitudes in Research

Albert W. Strickland, III

This paper discusses the use of cognitive entry behaviors and instructional techniques as a new avenue for researchers in science education to explore. The focus on cognitive entry behaviors is on learner aptitudes and the use of ATI results as a research tool. The instructional techniques discussed are the use of informational processing models. The paper supports the argument that future research in science education should employ the joining of these two areas to produce meaningful research.

In the preface to *Human Characteristics and School Learning* (Bloom, 1976) we find the following statement:

> Most students become very similar with regard to learning ability, rate of learning, and motivation for future learning—when provided with favorable learning conditions.

If this statement is true, this fact could have a significant effect on the shape of research in science education over the next decade. The meaning of the phrase "favorable learning conditions" and Bloom's instructional learning model (See Figure 1) are the focus of this paper.

The first part of this paper will be concerned with student entry characteristics, which will be referred to as learner aptitudes; the second part will focus on variations in instruction through the use of differing informational processing models.

In the development of effective instructional methods one problem has been paramount in reaching a real measure of success: How do we determine the most effective method for training large numbers of students possessing dissimilar patterns of abilities? One of the strategies usually employed has been to seek "the one best method of instruction." Fuller (1969) proposed that individualizing instruction for students was an important feature of effective instruction. Hereford

(1971) and Merrill (1968) viewed the varying of educational objectives, pacing and sequencing according to student characteristics as a possible mechanism for individualizing instruction.

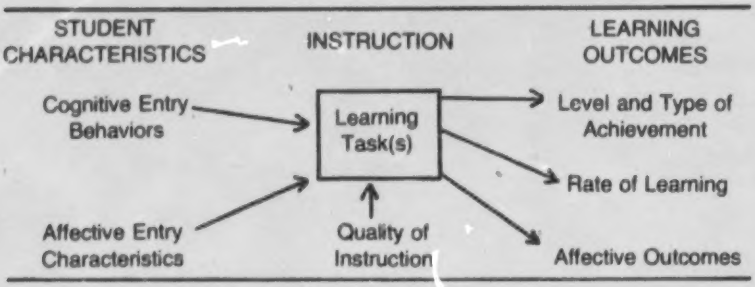

Figure 1. Instructional learning model.

However, learners differ and the search for the one generally superior method should be supplemented by a search for multiple ways in which instruction can be varied so as to fit the characteristics of learners (Cronbach & Snow, 1969, reviewed by Koran, 1973).

As Cronbach (1957) has observed,

> The treatments are characterized by many dimensions; so are persons. The two sets of dimensions together determine a payoff surface. . . Ultimately we should design treatments not to fit the average person, but to fit groups of students with particular aptitude patterns which correspond to modifiable aspects of the treatment. (pp. 680, 681)

The thrust of this statement is that educators should not ignore interactions between learners' aptitudes and various instructional treatments, but should *adapt* instructional treatments to learners' aptitudes. Cronbach (1965) has developed a theoretical framework to deal with the immense task of analysis of different aptitudes and differing instructional treatments. He has labeled these studies Aptitude Treatment Interaction studies or, more commonly, ATI studies.

The concept of Aptitude Treatment Interaction is not a novel idea in the scientific world. Environmentalists have been using this concept for some time. The concept of a single rank ordering applied either to organisms or environments ignores the fundamental principle that it is the demands of the environment that determine survival or elimination. Similarly, the current search of ATI is based on the premise that there is no one best educational environment suited to some general, average (individual), but that different individuals thrive in different educational environments suited to their own characteristics and needs (Koran, 1973).

An interaction between aptitude and treatment is present when one instructional treatment is significantly better for one type of learner, while an alternative treatment is significantly better for a different type of learner (Koran, 1973). More specifically, for instructional treatments to exhibit ATI, there must be different instructional methods. The instructional methods must teach to the same objective or criterion, and there must exist one or more aptitude measures for which regression of criterion scores on the aptitude are generally nonparallel.

Basically, there are two types of Aptitude Treatment Interactions that might result; they may be either ordinal or disordinal in nature (Cronbach & Snow, 1969). An ordinal interaction is present when the regression functions have different slopes, but one is superior to the other through the range of aptitudes being considered (see Figure 2).

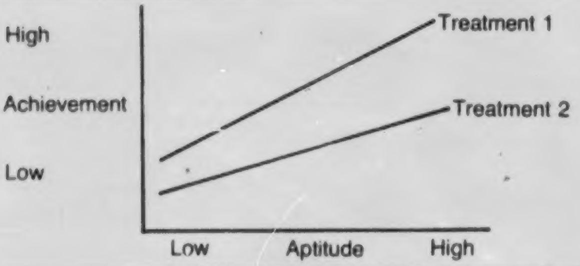

Figure 2. Ordinal interaction.

A disordinal interaction is one in which the regression slopes intersect within the range of the aptitudes being considered (see Figure 3). Such findings imply, in general, that different assignment of subjects on opposite sides of the interaction to alternative treatments is appropriate for maximizing learner outcomes (Koran, 1973).

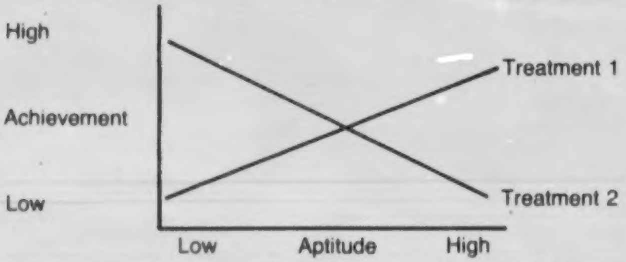

Figure 3. Disordinal interaction.

The general objective of ATI research is to match instructional methods or materials to selected learner characteristics. Therefore, unless one treatment is obviously best for all, some differentiations should be performed in such a way as to maximize their interactions with aptitude variables. A considerable number of studies in which ATI's have been deliberately sought provides initial evidence to suggest that subjects may learn more easily from one method than from the other (Cronbach & Snow, 1969; Berliner & Cahen, 1976). In addition, this method differs from subject to subject and that difference between treatments is related to learner characteristics.

For the purpose of aptitude by treatment interaction research, aptitude has been defined as *any* characteristic of the individual that functions selectively with respect to learning; that is, which facilitates or interferes with his learning from some designated instructional method (Cronbach & Snow, 1969). This formal definition allows consideration of such variables as task specific knowledge and skills, cognitive styles, personality characteristics, and heuristic strategies, as well as the more traditional cognitive ability variables.

One problem in the study of aptitude by treatment interaction, therefore, is the inordinately large number of learner characteristics that might be considered in adapting instruction to individual differences. Moreover, few of these differences have been shown to be correlated with specific learning outcomes under specific instructional methods in the particular population specified. In addition, there has been a comparative lack of precision in describing the task or treatment variables. For this reason treatment has been broadly defined for ATI research to include variations in structure, pacing, style, or modality of instruction, although eventually this definition should be expanded to include noninstructional situations as well (Cronbach & Snow, 1969).

The conduct of ATI research in public schools is an extraordinarily complex task requiring the integration of aptitude and instructional theory in the context of the theory of developmental stages and complex situational variables. If ATI research is to have an impact on classroom instruction, this task must be fully embraced and the solution translated into meaningful classroom instruction. Perhaps the next step is to join ATI research with some well-defined instructional models, analyzing which models maximize instruction for whom.

The Use of Instructional Models in Research

Berliner and Cahen (1976) examined many instructional models such as inductive versus deductive, structured versus unstructured, concept learning, mathemagenic strategies, and many others. These studies use aptitudes such as personality, cognitive ability, and demographic variables; many displaying disordinal interactions between treatment and aptitude.

Tallmadge and Shearer (1969) revealed that inductive and deductive treatments interacted with anxiety. Similar results were reported in numerous other studies (Tobias, 1968; Tobias & Abramson, 1971; Tobias & Duchastel, 1973). In these cases instructional modes varied and the effect of anxiety on learners was persistent.

While each of these studies moved forward in ATI research, there was the apparent need to more precisely define the instruction mode to more carefully utilize the set of learner aptitudes that were influencing the disordinal interactions.

Nuthall (1968) sought to answer the question, "Do differences in teaching strategies produce measurable differences in student learning, and are these differences related to significant student characteristics?" by designing an experiment that compared the effects of four different instructional strategies in teaching the meaning of two sociological concepts to high school students. Programmed instruction was used as the means to allow precise control of the sequencing of content, and the exposure of students to the instruction. The results of this experiment demonstrated that teaching strategy was meaningfully related to student learning and certain student characteristics contributed significantly.

However, Tobias (1968) reviewed the effects of programmed instruction (PI) and computer-assisted instruction (CAI) as vehicles for instructional modes interacting with various learner aptitudes. Tobias reported that many of the studies did not develop sufficiently distinct treatments and thus precluded the emergence of ATI's. More importantly, for the planning of this study, the PI and CAI instruction did not follow a consistent conceptual framework (e.g., the treatments were not theory-based or sufficiently different to create differential effects). Cronbach and Snow (1969), for example, have suggested the virtue of computer-assisted instruction as a means for stabilizing the instructional model, concluding that a precise theory based model would lead toward a more meaningful exploration of Aptitude Treatment Interactions.

Joyce and Weil (1972) presented several informational processing models; the concept attainment model (based on the work of Jerome S. Bruner), the inductive model (based on the work of Hilda Taba), the inquiry training model (based on the work of J. Richard Suchman), the biological science inquiry model (based on the work of Joseph Schwab), the advance organizer model (based on the work of David Ausubel), and the developmental model (based on the work of Jean Piaget). While each of these models deserves attention, there are others based on the works of Robert Gagne and Robert Rothcoff that could lead researchers to new vistas. If a selection of these models were to be properly defined for an area of instruction, perhaps ATI research could lead to some new conclusions about learning and individual differences.

An exciting new track for the researcher in science education is to explore the joining of instructional models and ATI research.

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Improving Science Education Through Instructional Technology

James D. Russell

The author defines instructional technology and relates it to the concept of humanism in science education. The historical development, characteristics and applications of five technologies of instruction are described—programmed instruction, the audio-tutorial approach, the personalized system of instruction, modular instruction, and computer-based instruction.

Just what is instructional technology? The Association for Educational Communications and Technology defines it as "a complex, integrated process involving people, procedures, ideas, devices, and organization, for analyzing problems and devising, implementing, evaluating, and managing solutions to those problems, in situations in which learning is purposive and controlled" (p. 166). Thus, instructional technology is more than the use of media such as films, videotapes, audio tapes and filmstrips in the classroom. Instructional technology is a systematic way of designing, implementing, and evaluating the teaching/learning process. The technology is based on specified outcomes (objectives), principles gained from research in human learning, and the use of both human and nonhuman resources. Mediated materials are assigned to the tasks that they can do best, such as the presentation of information or the demonstration of a skill.

Recently much has been heard about the need for humanism in science education. Many educators view humanism and instructional technology as being diametrically opposed (see Figure 1). However, as Fox and DeVault (1974) point out it is possible to develop an approach in science education that is both humanistic and technological (see Figure 2).

Let us look briefly at a high school chemistry course. The teacher has chosen an up-to-date textbook and assigns the students to read it chapter-by-chapter. At the end of each chapter all students answer the study questions and alternate problems. The study questions and problems are submitted to the teacher for review and evaluation. There is a quiz each Friday over the material covered that week. At the end of the six-week grading period there is a comprehensive exam over the content assigned during that grading period. In class, the teacher lectures on the content of the reading assignment; any questions are handled after class or by appointment with the teacher. During laboratory periods every student does the same experiment. The student must finish the experiment during the lab period and submit a worksheet and write-up at the following lab period. This science class ranks low in both the use of instructional technology and humanism (point A in Figure 2).

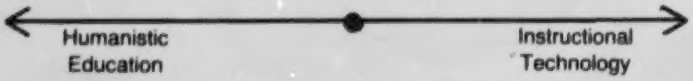

Figure 1. A common misconception toward humanism and instructional technology.

Now let us examine the physics program at the same high school. The course consists of 40 modules; each student completes 20 basic modules, 10 of which are electives depending on that student's interests and needs. Each module has stated performance objectives, a student study guide, and self-check questions. Some of the modules are paper-and-pencil programmed booklets, others incorporate slides and audio tapes, some are on videotape. The type of media is determined by the nature of the content and availability of materials. The students progress through the materials at their own pace. Each student is scheduled for a 10-minute conference with the instructor during every six-week grading period to review that student's progress.

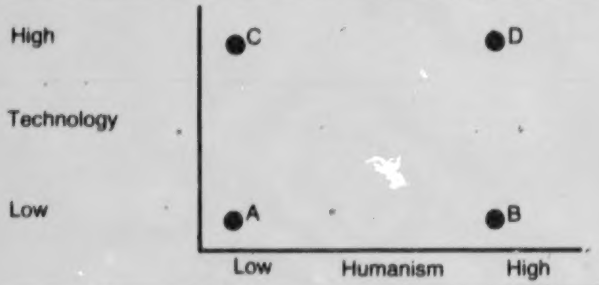

Figure 2. The relation between humanism and technology (after Fox & DeVault, 1974).

The assessment of student achievement is based on mastery tests, the student teacher conference, and special projects designed and conducted by the individual student. The laboratory phase of the course is handled in an Audio-Tutorial approach which integrates the lecture and the laboratory portions of the course. Periodically the instructor meets with small groups of students for discussion of debatable topics, review of group projects, and oral evaluation. Extensive records on the progress of each student are kept on the school system's computer, and this information is used to modify the student's plan of study for the course when necessary. Where should this course be ranked in Figure 2?

The writer considers the course just described to be at point D, since it is high in both humanistic concern for each student and also makes extensive use of instructional technology. Of course, it is possible to have courses that make extensive use of instructional technology but that have very little concern for humanistic education (point C in Figure 2). On the other hand, some science courses use very little technology, but are very humanistic with many group activities and much interaction between the teacher and the students and interaction among the students. A given approach is not "good" or "bad" according to where it falls on Figure 2; the quality of an approach is determined by success in terms of student achievement. However, students tend to demonstrate higher achievement in a class that ranks high in both humanism and in the application of instructional technology.

Programmed Instruction

One of the first attempts to apply instructional technology to the improvement of science education was through programmed instruction. Most of the early paper-and-pencil programs were designed to teach small units of subject matter. The research of Skinner and others in the middle and late 1950's led to the formulation of several teaching principles which became characteristic of programmed instruction—small steps, active student involvement, immediate confirmation or reinforcement, and self-pacing. In the broadest sense, an instructional program is a sequence of learning activities designed to help students attain a specific set of objectives. The instructional material has been modified on the basis of student tryout (learner verification) and the final version of the material is accompanied by validation data describing the performance of a specific group of students who have completed the program (Russell, 1972).

Several thousand programmed texts have been developed in the sciences. By themselves or in conjunction with other materials, these programmed materials can be used to teach part of a course or even entire courses. Many science teachers are using short programmed units to teach scientific concepts, principles, and terminology. Programmed instruction is particularly useful as enrichment instruction for motivated students. At the other extreme, some remedial learning can be accomplished by using programmed instruction. These materials also can be used in the science classroom to achieve a certain prerequisite level of competence or "entry behavior." Programmed texts also can provide a continuity of learning experience for students who miss specific instruction because they were absent.

The emphasis of programmed instruction, like all instructional technology, is on learning rather than on teaching. The teacher's function becomes one of prescriber, motivator, and resource person. Programmed materials are student centered. Early in the development of programmed instruction, it was recognized that, unlike a lecture or film, programmed materials can be adjusted to each individual's rate of learning. However, individualizing instruction can pose a serious problem—namely, determining the individual student's needs, interests, abilities, and aptitudes.

Because this individualization requires extensive testing and diagnostic study, measuring instruments need to be developed to examine the individual more thoroughly and more objectively. It is possible, however, to use a variety of programmed textbooks with different approaches to meet the same objective, thus capturing the interest and meeting the needs of a greater number of students. Since programmed materials adapt to the learning rate of the individual student, many persons consider them to provide humanistic learning. At the same time they incorporate the principles of instructional technology, so would rank near point D in Figure 2.

Audio-Tutorial Approach

During the early 1960's Postlethwait (1969) began using audio tapes as a means of programming the instruction in his college botany course at Purdue University. The approach includes the use of a learning center with individual study carrels equipped with audio tape playback machines, 8mm movie projectors, many of the real objects (plants, microscopes, etc.) being studied, and any additional materials needed to facilitate student learning. Independent study, observation of materials, and experimentation are done in the study carrel or at the demonstration areas in the learning center. An instructor whose purpose is to humanize the learning, is always nearby to answer questions and assist in the learning process. Many science educators now use this approach. Audio-Tutorial (A-T) instruction has demonstrated its success at the elementary, junior high, high school, and college levels.

The central focus of the A-T approach is the individual student using audio tapes designed to direct him or her through a variety of learning activities. The taped presentation is not a lecture, but a tutorial conversation by the instructor. Each student paces his or her study according to individual ability to assimilate the content presented. The exercises in the lessons actively involve the student, and the headset as well as study carrels minimize distractions. Because the lessons are recorded on tape, make-up lessons and review sessions are easily arranged with minimum effort (Russell, 1978).

There are three basic components in the Audio-Tutorial system: (a) an Independent Study Session, (b) a General Assembly Session, and (c) a Small Assembly Session.

The Independent Study Session is conducted in the learning center. The objectives are stated in behavioral terms and listed in a suggested sequence for study. An auido tape "tutors" the student through a sequence of learning activities. Segments of the tape can be replayed as often as necessary for clarification. Demonstration materials are made available at a central location. Motion and color are provided by 8mm movie projectors and videotapes.

The General Assembly Session has no fixed format. It can be used for the same fundamental principles of learning underlying programmed instruction. The system focuses on the presentation of information, student performance, and immediate confirmation regarding the adequacy of the student's response. Keller's concern for frequent assessment of student achievement and the need for different rates of student progress resulted in a mastery evaluation system and student self-pacing. The task of the PSI instructor is to provide brief, sequential study materials with specific objectives. The success of the system is highly dependent on classroom management techniques. There are five key components in the PSI approach: written materials, individual mastery, student self-pacing, motivational activities, and student proctors.

The written materials generally include conventional textbooks, study guides, and handouts for presentation of information. Even with the emphasis on printed materials, PSI courses in science incorporate field trips, audiovisual materials, and even computer terminals.

Individual mastery requires that each student attain a preset level of achievement on each unit before he moves on to the next. A consequence of this component is student self-pacing which has each student learning and progressing at a rate which is comfortable for him or her. Some lectures, films, and field trips are used as motivational activities since it is a requirement that a minimum number of units be completed before the student can participate.

The most distinguishing characteristic of the Keller, or PSI, plan is student proctors. Proctors may be students who have satisfactorily completed the course in a previous semester or they may be students who are currently enrolled in the class. After a student has completed a unit, he can assist those students who have not completed the unit. The proctors are really the ones who personalize the course. They interact with the students on a one-to-one basis, evaluate quizzes and laboratory reports, and provide tutoring when necessary. Proctors often can explain course content to their peers in a more understandable manner than the instructor can. Proctoring is a highly reinforcing experience and an educational one as well. Perhaps this is exemplified by the old adage "you never really learn something until you have to teach it to someone else" (Sherman & Ruskin, 1978).

The system is designed to guide learning using a minimum of instructional technology but a maximum of humanistic qualities. It would fall in the area of point B in Figure 2. PSI has been applied to science instruction at all levels, particularly in the fields of social science and psychology.

Modular Instruction

The concept of a small unit of subject matter that could be treated coherently as an individual topic and could be conveniently integrated into a course of study was proposed by Postlethwait in 1968. He originally called these units "microcourses" but later adopted the term "minicourse" since the units were, in fact, small courses. Similar small units of instruction are being developed under titles such as "concept-o-pac," "instruct-o-pac," "unipak," "learning activity package (LAP)," and "individualized learning package (ILP)." The generic term that has emerged in the literature for all these terms is "module."

A module is an instructional package dealing with a single conceptual unit of subject matter. The learning activities are often presented in a self-instructional format, but modules can be designed for small groups or even an entire class. Since the modular package may involve materials that are portable, the students can take it to the library, to a study carrel or to their homes. The student controls the rate and intensity of study. The length of a module may vary from only a few minutes of student time to several hours (Russell, 1974).

One example of the application of modular instruction to the elementary curriculum is "shoe box science." The teacher includes in a small container, such as a shoe box, all the materials that the student needs to explore a topic such as "magnetism" or "seeds." For young students with minimal reading skills the directions and guidelines can be recorded on a cassette tape. The activities can also be shown in pictorial instructions. Evaluation of student learning can be measured by the teacher through oral discussions with the students. For older students the objectives and activities can be duplicated on a worksheet or study guide. Science modules can be used in the elementary school as elective activities for students who have completed their assigned materials. The modules can be used as rainy day activities when the students cannot go out to recess. Some teachers allow the students to take the modules home to share with their brothers, sisters, and parents.

For older students, the modules can be structured around a chapter in their textbook or a laboratory exercise. They can incorporate a variety of instructional activities and media, such as reading from books and articles, examining charts and graphs, viewing films and slides, listening to audio tapes, examining demonstration materials and realia, performing experiments, and participating in discussions.

Modules can provide freedom and flexibility for both the students and the teacher in the science classroom. The small units of subject matter can be arranged in a variety of sequences. One module might meet part of the requirement for several courses. The student might have the option of completing any 10 of 15 or 20 modules to meet the requirements of a "total course." The student might also be free to select the order in which he studies some of the modules.

Computer-Based Instruction

The computer, with its almost instantaneous response to student input, its extensive capacity to store and manipulate information, and its unmatched ability to serve many individual students simultaneously, is becoming more and more widely used as a technology of instruction in the science classroom. The computer can record, analyze, and react to student responses that are typed from a typewriter keyboard or indicated with a light pen on a screen.

In addition to presenting instructional materials and exercises, the computer can store information pertaining to each student, including aptitude scores, learning style, and previous achievement. When a student's name or identification number is typed into the computer, the student's records can be accessed, and the computer can without delay present review material or it can resume exactly where the student stopped previously. The student's records also can be made available to the teacher for a progress evaluation (Russell, 1972).

With the recent introduction of "mini-computers" and microprocessors, the cost per student hour of instruction on a computer system is decreasing. In addition, the initial cost of computers themselves is decreasing. Consequently, the use of computers in the science classroom is increasing and will continue to do so. Some computers are even available in kit form and can be assembled by the students. Presently, delays in implementing computer-based instruction and using computers for computation activities are due to the lack of teachers properly trained to design computer-assisted instruction or to train students to program computers.

In science education the computer can perform many roles and add new dimensions to learning. The most obvious applications are solving numerical problems and analyzing data gathered in the laboratory. The computer also can be used for drill and practice, tutorial assistance, inquiry training, and simulation of laboratory exercises.

One of the most extensive computer-based instructional systems is PLATO (Programmed Logic for Automatic Teaching Operation) based at the University of Illinois. The PLATO system was first introduced in 1960. Today there are more than 400 programs available in science which constitute more than 250 hours of instruction. Like all CAI programs, PLATO lessons are written to accommodate individual rates and learning styles, as well as to provide for acceptance of student-constructed answers. PLATO includes a variety of graphic and computational capabilities and has been used in public schools, community colleges, and universities around the world. The cost for using the PLATO system can be less than one dollar per student hour on the terminal.

Summary and New Directions

In this article we have explored five instructional technologies that are being used to improve instruction in science. They have been described in terms of their potential in both the technological and humanistic dimension. Several characteristics and principles underlie all of the technologies—specified objectives, active student participation in the learning process, frequent evaluation of student achievement, and immediate feedback to the learner. Their success or failure is measured by student achievement in the science classroom.

Just as several of the technologies have evolved from the basics of programmed instruction over the past two decades, new and different approaches to instruction will continue to evolve from these modern modalities. The science teacher must be aware of the wide variety of technological approaches to teaching science and at the same time must not forget the importance of a genuine humanistic concern for student needs and interests.

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Science Curriculum Content Selection

Alfred De Vito

Science curricula in the United States are and have been for a long period of time a "mixed bag." Their delineations have been predicated on available funds from both local and national sources, geography, the prevailing aims and goals of the educators who conjured up the curricula, and the various interpretations assigned to the learning process of the students as they proceeded through those curricula. This presentation concerns itself with the science curriculum and the factors that influence it. While specific science content is not specified, desirable outcomes of a science curriculum are enumerated. Along with stated goals for the learner, a section is devoted to the unique aspects of science and how this uniqueness contributes to the learning process. Another section covers the bases for content selection in the elementary, middle, and secondary school science curricula. A final note cautions for vigilance and constant monitoring of the science curriculum to maintain selected, predetermined goals.

Over the past 20 years much that has happened in public school science instruction has been good. Numerous federally funded projects at both the elementary and secondary school levels have pointed the way for what might be generally accepted as appropriate science instruction in the public schools. Fallout from these projects has carried their spirit and intent into commercially prepared texts, visual aids, and a wide variety of hands-on equipment. Currently, much good material is available.

At this point, one might ask: Where do we go from here with the science curriculum? Are we going back to the basics? Did we ever leave the basics?

Before discussing the factors that affect the development of today's science curriculum, the reader may find it helpful to review some former practices in science curriculum development. There was a time (early) in this author's teaching career when the immediate public school supervisor informed the author that the community served by the school's teachers was unique. The supervisor further explained that this uniqueness was to be reflected in a curriculum tailored to meet it. This writer believed that it was possible to develop a curriculum tailored to the unique needs of the community. And believed with enthusiasm, too! Weekly, between 3:30 and 5 p.m., huddled over a bag of culled-over doughnuts, a curriculum, or segments thereof, was concocted by well-intended professionals. One year the science curriculum was revised; the next year the mathematics curriculum, and so on. The teachers became better organized and more proficient. They learned to play the game. The system was replicable.

First, they would ferret out the most recently published books on the particular topic. They were always anxious to see what was developed by commercial authors and what evolved as a common denominator in the field. Next, using the town as a focal point, they swung an arc on a map to encompass several major neighboring towns, then checked to see what they were doing in the areas of concern. This was followed by a check with neighboring universities to see what the experts were currently recommending. All this information was thrown into the pedogogical hopper and cranked. Out popped the "unique" curriculum. In reality, it was not very unique. Also, it rarely was used.

What, then, should determine the curriculum content? Determination of the science curriculum is dependent on several factors. These factors are the goals of society, the structure of the sciences, and goals for the learner. The goals of society are usually broad and pervade the entire curriculum. The structure of science, while seemingly well delineated, is confounded in its presentation by the nature and geographic mobility of the learner. These factors are discussed below in more detail.

The Goals of Society

The structure of a democratic society demands that its citizenry be responsible, competent, and ethical. Science education can assist learners to understand society's dependence on scientific and technological achievement, and it can help students understand how science is basic to living. Furthermore, students should be given an understanding of the relationship between basic research and applied research and of the interplay between technological innovations and human affairs.

Desirable attributes of a science curriculum should be concerned with:

1. The intellectual parameters wherein the acquisition of scientific knowledge, the communication of scientific knowledge, and the use of scientific knowledge in the solution of problems are reviewed and stressed.
2. The social parameter wherein science, the scientist, and the general public interact on a scientific foundation at the local, state, national, and international levels, with the question of survival being paramount.
3. The personal parameter wherein personal fulfillment is reached from the applications of science in the home, and to the individual as a consumer, and perhaps as a vocation. Science should be stressed so that there is recognition of the emotional, ethical, and aesthetic contributions and consequences of the disciplines.

Science education should assist individuals in acquiring the skills, the knowledge, and the emotional adjustment needed by them to relate successfully to themselves and to the world around them. Individuals should be afforded the maximum science education so that they can manage their personal and collective lives to the best advantage. Also, such emphasis should enable them to survive in the face of change.

The Structure of Science

Science is considered by some to be a many splendored thing. By others, it is considered a "many horrendous" thing. Regardless of which view one holds, and assuming that science and science instruction is valuable, how does one best proceed in the instruction of science? It would seem logical first to consider the structure of science. Is there something intrinsic in the structure of science that clues us in some predetermined pattern for maximum instruction?

Physics has long borne the mantle of the "pure" science, and, perhaps, rightly so. Physics is the primary root of science. Chemistry builds on physics, biology builds on physics and chemistry; earth science builds on physics, chemistry, and biology. All, except physics, are derived sciences. Earth science is the most derived science with its roots steeped in physics, chemistry, and biology. This relationship is depicted diagramatically in Figure 1.

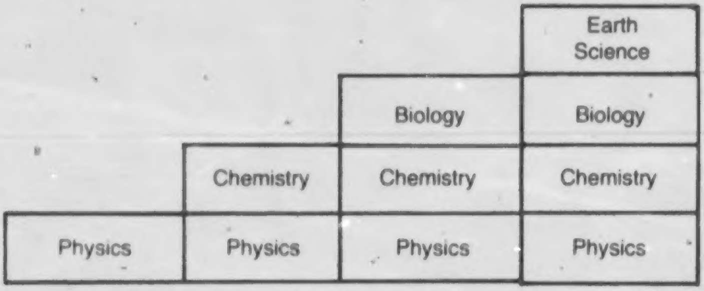

Figure 1. The building blocks of science.

It would appear, then, that one properly should start science instruction in physics and progress to chemistry, to biology, and then to earth science. The logic of this approach is lost when one considers the ability and the interest of students at various grade levels. Biology appears to win out as the most popular science discipline. Earth science, while considered a relatively newcomer to the curriculum, probably would run a close second to biology. Chemistry and physics would register way low in a course preference contest—physics probably losing out to chemistry. Perhaps this is why in the high school curriculum, if course elections are made by students, biology generally comes first, then chemistry (or physics) and, perhaps as an honors course, an earth science class (this coming last since many schools do not even offer earth science). Indeed, there are many variations to science content selection. However, even though these curriculums may be vastly different from one another, they are not necessarily contradictory, instead they may complement the needs and abilities of each individual school's teachers and students. The above described approach of "biology first" is sometimes referred to as a "time tested science curriculum." Such an approach appears contrary to the structure of science. Should science's structure be neglected in the curriculum? It appears that it has been.

In practice, elementary school science is more or less incidental and descriptive despite some exotic learning titles such as "Concepts in. . . ," "Models for. . . ," "Structural. . . ," and so forth. Junior high school science instruction is usually taught as a broad discipline; in high school science becomes more specialized under discrete titles such as biology, chemistry, or physics.

Goals for the Learner

Science education should extend the individual's ability to learn, to relate, to choose, to vote, to communicate, to challenge, and to respond to challenges so that the individual may live with purpose in the world of today and tomorrow and achieve pleasure and satisfaction in the process.

Science education is a human enterprise—it is that experience wherein individuals strive to explain natural phenomena. This human enterprise includes the on-going process of seeking explanations and understanding of the natural world. Also a part of this enterprise is the product of the seeking process. That product is the content or facts of science. Content is the product of science, but is not in itself a science. Science is both *process* and *content* (or product).

Of course, a science curriculum should present appropriate science content. However, companion to content acquisition should be process development preparing students who are capable of observing with discrimination, of classifying observations and other information, of quantifying their observation of graphical communication, synthesizing and modifying explanations, and of making and testing predictions against theory.

Perhaps more germane to the learners than science content knowledge are the personal accruements that result from an involvement in a study of the sciences. This brings us to the question, What is unique to science? Appropriately, students often ask, "Who needs science and why?" Their question is not answered simply by stating that they need to know the content of science. If science is to gain stature in the eyes of curriculum discontents, then it must be promoted on the basis of what science can do for the individual through the personal use of scientific thought. That idea leads to the question, What is unique to science?

Each science discipline has its particular approaches, tools, and methods for discovery and ordering information. However, common to all is the process of experimentation. Experimentation in the process of establishing the proof or existence of something or in finding a solution to a problem is unique to all areas of science. Concomitant with the acquisition of the skill of experimentation, the individual should acquire from a study of science such attributes as

1. The questioning of all things;
2. A consideration of premises, impinging variables, and the consequence of proposed action;
3. A spirit of demonstrative verification;
4. A search for data and their meaning;
5. A respect for logic, and the development of a strategy for inquiry.

Ancillary to the paramount assets of personal scientific thought, the individual should gain insight into the relationships between science, society, technology, and philosophy. These assets and insights are adjunct to an acquisition of the concepts and principles of science.

Content Selection in the Science Curriculum

Generally speaking, elementary school science should be exploratory in nature. The nature of the learner, rather than the structure of the sciences, dictates the curriculum. The curriculum in the primary grades should concentrate on the development of the basic process skills of science, such as observing, classifying, measuring, communicating, inferring, predicting, and space/time relationships. These skills should be developed around "hands on" science activities that stimulate curiosity and enthusiasm, that capitalize on the creative nature of young children, that foster continuous creativity, that nurture the habits of systematic observations, that initiate and sustain qualitative and quantitative thinking and representations, and that promote the development of scientific thought. The acquisition of a science vocabulary, while important, should not be acquired at the expense of ideas. Ideas come first; the vocabulary of science comes later.

The intermediate and middle school science curriculums should center on the enlargement of and the continuity of science. These grades should concentrate on content acquisition as a vehicle to the development of the integrated process skills such as experimentation, controlling for variables, collecting and interpreting data, and building of scientific models.

The vitality of science should be promoted by constantly presenting the challenges of science. Inquiry and the spirit of searching for answers should not be sacrificed at the expense of the tedium of science. This is not to mask the tedium of science. The tedium (and there is much of it in the quest for answers to scientific problems) is tolerated best when the attributes of science are firmly anchored in the learner's mind.

Whereas science content in elementary school curriculum is more or less incidental in structure and descriptive in nature, in junior high school curriculum science is treated as a broad discipline. For many students, this is the last engagement ever with formal science instruction. Junior high school is a critical period in their education. If we pay homage to the validity and importance of such things as "goals for society" and "goals for the learner," then we are indeed being remiss in our mission by practicing the current methods of science instruction.

The junior high science program generally can be interpreted as a weak transition from elementary school to senior high school science. Junior high school science teachers should be the best trained of all our science teachers. They need to be the most versatile because of the diversity of science, the vast maturational range of students at this point of their development, and the fact that for many students this is the last close contact with science. In addition, if educators are to satisfy all the educational and personal goals attributable to science instruction, junior high school is the time and place. And yet, most universities do not offer bonafide junior high science teacher training programs. Therefore, where the best is needed we often find well-intended but inadequate teachers of science.

In senior high school, science instruction becomes increasingly specialized, and the "time tested science curriculum" is offered. This approach is usually not predicated on a K-9 enlarged, continuous, and coordinated science program. Usually too much material is contained and coverage is attempted in too many areas of any one discipline. Undue stress is placed on content and technology at the expense of the process goals. While in any program "good" students do well and "poor" students do poorly, in current science programs students often are not fully challenged because the courses rarely portray how science is practiced.

Constant Monitoring

In retrospect, we never left the basics. Educators, in their eagerness to be all things to all people, tried to accommodate every voice. New emphases resulting from this response are much in evidence. Little was left out of the science curriculum. Plate tectonic in the third grade? Fine! DNA and RNA in junior high? Why not? More was piled on and packed in than most students could handle in a life time.

Someone once said, "Things must change so that they can remain the same." And so the curriculum must change, but with careful, constant monitoring. Priorities must be delineated. Given an exponentially increasing body of knowledge, the science content must be prioritized in terms of appropriate science for discrete grade levels and discrete student groups. Physicists, science educators, and teachers need to agree on appropriate physical science topics for students at the elementary, junior, and senior levels. This would need to be delineated in other science disciplines as well.

Psychologists, educational psychologists, science educators, and teachers need to examine this established content delineation and establish a hierarchy of science instruction in concert with validized learning theories.

Society—composed of parents, educators, and other interested parties—needs to monitor and, where applicable, adjust the goals to see that predetermined and previously agreed upon goals are being met and, when desirable, altered.

The capstone to any science instruction should be the capacity of an individual to relate sensitively, to think divergently, and to perform imaginatively in personal confrontations with people and ideas.

For every complex problem there is usually a short, simple answer—unfortunately it usually is the wrong answer. The right answer is the one we want badly enough to work hard enough to obtain. Such should be our attitude as we science educators continue to improve science curriculums.

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Readability of Science Materials

William G. Holliday and Carl Braun

The objective of this article is to describe readability assessment methods used in science education and to summarize reported readability estimates of science textbooks and recommended strategies for reducing the readability load of such materials. Furthermore, descriptions of recent work in reading and science education and specific suggestions for future research are summarized expressly for those interested in improving the readability of science materials for classroom use. Two conflicting conclusions are drawn regarding the subjective and the formula readability assessment methods. First, those investigators using subjective judgment methods found that the evaluated science materials were too difficult for the intended users. In contrast, investigators applying a formula to the same materials found that the sampled textbooks were generally at the difficulty levels described in the teacher's guides. It is generally concluded that more theoretical and research work is needed to help teachers in assessing the appropriateness of science materials and to assist students in comprehending explanations of sophisticated content.

A readability index is an estimate of the reading level of a particular set of printed matter. These readability (or difficulty) estimates are particularly helpful to teachers in assessing the reading-level appropriateness of science textbooks for groups of students and for individual students with special needs. Recent theory and research has suggested to textbook and program designers some guidelines for assessment of readability of instructional materials and means by which instruction can be designed to reduce readability obstacles for the learner. This paper describes three assessment methods, then summarizes reported readability estimates of science textbooks and recommended strategies for reducing the readability load of such materials. In addition, summaries are presented describing recent work in reading and science education for those research and development people interested in improving the readability of science materials for classroom use.

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Readability and Science Curricula

A review of research and curricular literature reveals that science educators have focused little attention on assessing or directly improving the readability of science materials. However, researchers have examined numerous indirect devices (e.g., graphic inserts, advance organizers, behavioral objectives, and study questions) for improving students' probability of comprehending a textbook (see reviews by Faw & Waller, 1976; Holliday, 1973). Undoubtedly, these and related research domains are worthy of inquiry (Holliday, 1976). Yet, there is a dearth of literature focusing on ways of assessing the readability of science resource materials and on identifying organizational or structured writing patterns best suited to accommodate curricular objectives and individual student differences. This lack of enthusiasm for involving children in appropriate reading activities within comprehensive science programs is evident in the descriptions of science curricula by reviewers and publishers.

Barriers to selection of materials of suitable readability may account, in part, for the lack of enthusiasm on the part of science educators to involve children in any reading activities. For example, a popular document developed by the Far West Laboratory (Hutchins, 1970) accurately describes one of two major similarities among the "new" elementary school science curricula, "They help to create a laboratory environment by providing kit materials and related exercises for experimentation, rather than supplying reading matter." Similarly, commercial ventures such as Houghton Mifflin's *MAPS* (1974) and Addison-Wesley's *STEM* (1972) programs deemphasize the reading of science materials relative to commercial science curricula of previous decades.

No one argues against the importance of involving students in activity-oriented curricula. However, this orientation commonly results in negligible use of reading resource materials in the science classroom. Such curricular deemphasis places students at a distinct disadvantage in their subsequent science programs and in their adult years. In short, it is time science educators attended in general to the development of adequate reading components within curricula and focus some particular attention on assessing and investigating the readability characteristics of textual matter.

There are at least three factors that must be considered in assessing readability if the teacher is to employ such knowledge in matching readability with appropriate instruction. First, knowledge of the level of readability is essential, e.g., is the general level of material easy or difficult? Second, knowledge of specific readability features that account for the difficulty level is important. For example, the difficulty of the material may result from the author's use of difficult vocabulary, long, highly-elaborated sentences, poor organization, dearth of subheadings and graphic materials, or a combination of any of these features. Knowledge of such features is essential if the teacher is to reduce the readability obstacles for students through appropriate instruction. Third, while knowledge of general readability levels is essential, the teacher should be aware of individual differences in coping with materials. The amount of prior knowledge, for example, which the reader is able to bring to particular textual material will enhance his chances of success with the material irrespective of the "readability level" of the material.

Three Readability Assessment Methods

The general means of estimating the readability of science materials are to analyze the subjective judgments of students and experienced teachers, to apply a formula evaluating selected prose variables, or to administer to students a sampling of textual material with deleted words (cloze test). Each method has a unique set of assets and liabilities.

Subjective Judgment Methods

Science educators at all levels generally have chosen the subjective method for reasons of convenience and training. Klare (1974-1975) has cited many investigators who claimed that seemingly inaccurate and unreliable judgments were as valid and consistent as readability formulas and cloze methods. In fact, evaluators exposed to training programs can rank-order the readability of numerous textbooks with a higher degree of accuracy relative to the application of readability formulas. Another possible reason that science educators apparently favor this qualitative method rests in the inherent nature of science textbook language. Simple qunatitative methods of assessing readability usually are based on narrative prose written in the active voice and containing many modifiers and qualifiers. However, analysis of science materials suggests a predominance of terse expository patterns often written in a relatively complex style. For example, Gage (1974) presents quotations from biology and chemistry textbooks that clearly illustrate the awkward language used by many authors of science books.

On the other hand, there are many problems in relying solely on subjective quantitative methods. First, few science educators are adequately trained to assess a text's complexity, including the analysis of semantic and syntactic variables in terms of reading grade or reading age estimates. Intuitive judgments by untrained educators are of unknown quality and are vulnerable to obvious questions of rater realiability and validity when such judgments are used as the sole measurement procedure. Second, satisfactory rating methods require much more time and effort than do other methods because two or more raters are necessary to assess the readability of large portions of material.

Readability Formulas

Perhaps the single most practical method of assessing readability is the application of one of the many predictive formulas described by Klare (1974-1975). Such formulas require the determination of semantic and syntactic attributes of text samples and then the application of these values to a regression equation or a standardized graph. Science educators typically have chosen Fry's (1968) Readability Graph to estimate the level of difficulty of science textbooks as shown in Table 1. Essentially, Fry's syllable count method requires the evaluator to assess the average number of sentences and syllables for every 100 words in a text sample. These determined values are then plotted on a two-dimensional graph containing zones indicating the probable grade level associated with the printed materials. According to Klare (1974-1975), Fry's formula is reliable and valid within a wide range of grade levels. Furthermore, this formula has the advantage of correlating highly with more complex readability estimates while requiring a minimum of linguistic expertise and operational time.

Table 1
Descriptive Studies Evaluating Popular Science Materials

Investigator	Level of Education	Method	Selected Findings
Casey (1977)	Secondary	Subjective and cited authority	Science textbooks were written in difficult-to-understand manner.
Dawson (1974)	Junior high	Subjective and possibly an experimental study	Using ISC materials was appropriate and improved students' ability to read relative to a "control group."
Froese (1971)	Sixth grade	Cloze procedure	The 12 science programs generally were at the level of the intended user.
Gage (1974)	High school	Probably subjective	Chemistry (e.g., *Chemistry: Experimental Foundations)* and biology (e.g., BSCS—*Biological Sciences: Pattern and Process)* textbooks contained awkward sentence structure.
Gilbert (1972)	Elementary	Spache, Dale-Chall, Lorge and Fry indexes	The 10 science programs generally were found to be at the grade level of the intended users.
Kennedy (1974)	Secondary	Fry's Readability Graph	Evaluated programs (ESEP, IIS, ISCP, ISCS and PSG) were generally within one grade level of the target population.
Newport (1965)	Elementary	Spache and Yoakam indexes	The 9 science programs generally were at the level of the intended user.
Schneider (1977)	Elementary	Systematic content analysis	Five major publishers' science programs were formed to cover the traditional physical science concepts and to present concepts using similar approaches.
Telfer and Moore (1975)	Ninth grade	Probably subjective	Biology textbooks were too difficult due to vocabulary, sentence construction and chapter structure. *Scientific American* was even more difficult.
Thelen (1974)	Secondary	Probably subjective	Science textbooks were reported by teachers to be too difficult for their students.

Fry (1977) has recently written a clear, unambiguous, and concise article on how to apply his revised formula to printed materials. It is recommended that science teachers evaluating instructional materials become acquainted with this simple two-variable formula. However, the authors do not recommend its sole use in evaluating science materials nor its sole use in research work requiring a description of the readability of comparative experimental treatments. Other special-purpose formulas should be used where maximum predictive validity is of critical importance.

Word-list formulas also constitute a common means of assessing readability and seem to produce slightly higher predictive indexes than do word-count formulas. However, word-list methods require more time and effort, especially for material in which evaluators must count the number of words (in a prose sample) that do not appear on a long familiarity list. Fortunately, most word lists are of reasonable length because people ordinarily repeat the same few words with surprisingly high frequency. For example, Klare (1974-1975) reported that 10 words constitute as much as 25 percent of college freshman writing, and that 100 words constitute as much as 95 percent of adult telephone conversations. In contrast, analysis of science materials frequently reveals many "unfamiliar" conceptual and process words not on readability word lists. Since the word-list variable is more predictive than the syllable-count method used by Fry, word-list formulas such as the Lorge (1948) Formula and the Dale-Chall (1948) Formula logically would produce indexes of higher predictability. However, the practical differences between the syllable-count and the word-list methods are likely trivial in most classroom cases.

Cloze Test

The third method of assessing readability is the recently popular cloze test. This procedure requires the evaluator to select a minimum of 250 running words from a text sample. In addition, the first and last sentences adjacent to the sample are presented in their entirety. Then, one of the first five words from the second sentence is randomly deleted and replaced with a blank (15-20 spaces on the typewriter). This method is continued until every subsequent fifth word is replaced with blanks of equal length. Students are asked to predict the 50 missing words by making contextual inferences from the remaining words.

Thelen (1974) describes guidelines for analyzing individual student cloze scores as related to difficulty levels of science materials. Students unable to complete 40 percent of the cloze blanks likely will be frustrated and troubled by similar reading materials. Students receiving scores of between 41 and 60 percent will learn and function efficiently given a text of equivalent difficulty. Students able to complete more than 60 percent of the blanks probably will find such printed matter easy to understand and score at a high level on a typical achievement test.

Pupils' performances on a cloze test are good measures of their ability to comprehend reading material (Thelen, 1974). In fact, this procedure now is used as a criterion in developing readability formulas. Klare (1974-1975) and Thelen describe cloze development work by Bormuth in which large numbers of cloze tests on a diverse set of topics were administered to a wide variety of students.

Bormuth used this data to evaluate the predictive validity of 169 variables and to develop 24 special-purpose readability formulas. Similar efforts using science textbooks would contribute to the development of special-purpose formulas and reliable tests designed to evaluate the readability load of such printed materials.

Individual student performances can also be estimated using the cloze test in accommodating specific learner differences. However, this test is a time-consuming method of evaluating groups of students and does not always constitute the most efficient way of estimating readability, since syllable-count and word-list formulas correlate highly with cloze scores obtained from large student populations. Yet, those interested in comprehensively evaluating science materials, assessing individual student performances or doing readability research will likely find the cloze test the most valuable method of assessment.

Reports of Textbook Assessments and Techniques in Facilitating Reading Comprehension

Readability studies in science education have mainly reported difficulty levels of popular textbooks, and also have recommended techniques apparently useful to teachers in facilitating student comprehension of reading materials. Two conflicting conclusions can be drawn regarding the subjective and the formula assessment methods as described in Table 1. Those investigators using subjective judgment methods found that the evaluated materials were too difficult for the intended users. In contrast, investigators applying a formula to the same materials found that the sampled textbooks were generally at the difficulty levels described in the teacher's guides. Consequently, it would be useful to investigate in a comparative fashion the application of the three assessment methods on an elementary science program such as Addison-Wesley's STEM curriculum and on a secondary science textbook such as Otto's, *Modern Biology*. Syllable count and word-list count formulas could easily be used to assess such materials. However, comprehensive and systematic sampling techniques would be required to assess large numbers of teachers and students. Results from such a descriptive study would provide a rational basis for comparing validity and reliability attributes of each method and a basis for developing readability measures specifically designed to estimate science materials.

Second, the learning techniques shown in Table 2 were found by reading and science educators to reduce the readability load of science materials. Yet science educators have focused little attention on the development, implementation, and evaluation of such ideas, as evidenced by their patent absence in research journals, university methodology books, and teachers' guides. Clearly, more research work is needed to substantiate the validity of these techniques. For example, there exists a need to investigate SQ3R strategies, which are used to facilitate students' reading comprehension, because of their wide-spread use by students who are reading content materials. Briefly, the SQ3R procedure entails a five-step learning process. First, students *survey* or preview material by identifying the author's purpose and locating difficult words. Second, students ask *questions* about the material, often beginning with words like where, what, when, how, and why. Students then *read* the passage and identify the major

Table 2
Techniques Apparently Useful in Reducing the Readability Load of Science Materials

Educator	Level of Education	Selected Recommendations
Cornett (1975)	Ninth grade	1 Encourage students to read anything related to science while the teachers also read about science 2 Place in the classroom a wide variety of high-interest books and magazines
Esler and Merritt (1976)	Elementary and middle	1 Provide observational and manipulative science activities 2 Ask students to describe observations and experiences while writing their sentences on the board 3 Synthesize a story from these sentences and use the passage to teach skills common to science and language arts
Gage (1974)	Secondary	1 Dismantle complex sentences for students 2 Teach to students the patterns of language used by science textbook authors 3 Analyze and discuss new words with students 4 Encourage students to use the SQ3R strategy
Hittleman (1978)	All	1 Help students recognize textbook presentation patterns 2 Assist students in understanding adjunct graphic displays and their relationships to textual material 3 Pose questions to students about reading material thereby guiding their reading and thinking efforts 4 Use the SQ3R strategy 5 Teach students how to obtain information from their textbook and other reference books
Karlin (1975)	Elementary	Similar to those points described by Hittleman (1978)
Spache and Spache (1973)	Elementary	Have students systematically study science textbooks using such approaches as the SQ3R strategy
Thomas and Robinson (1972)	All	1 Use general strategies in studying content and 2 Special strategies in reading science laboratory manuals (e.g., use inserted "SLOW, STOP and WARNING" highway signs, bold type print, underlining techniques and various kinds of diagrammatic arrows)
Warren (1975)	Secondary	1 List and define new words and explain them to students before reading assignments 2 Produce verbatim audio tapes (with inserted study questions) of printed materials 3 Have students read the text while listening to the tapes

ideas; *recite* these ideas to themselves; and *review* the passage to facilitate understanding and memory of important ideas.

The following recommendation represents one way of comparatively evaluating variations of this learning technique. Students could be assigned to SQ3R strategy treatment groups, be instructed in learning the strategy variations to a criterion level, be requested to apply their learned skills to differing organizations of the same science content, and finally be administered an achievement post-test. A counterbalanced post-test-only control-groups design would yield comparative data on the effectiveness of strategy variations in terms of different organizational patterns.

Reducing Readability Load by Using Different Content Structures

A major goal of science educators is to provide students with science reading materials that will facilitate higher-order comprehension of sophisticated concepts and processes. Yet few researchers have directly attacked this problem. Corey's (1977) study represents an exception and constitutes one of few experimental studies evaluating the effectiveness of two organizational presentations of the same information. Here, six scientific journal articles were revised by lowering their level of reading difficulty and then experimentally comparing these revised versions with the original journal versions. Corey concluded that ninth-grade biology students can better comprehend material altered in style and vocabulary. Even though Corey's independent variable and theoretical rationale were inadequately described relative to similar studies in reading (see Anderson, Spiro, & Montague, 1977), his investigation represents a direct attempt to identify appropriate content composition and structure for a specific group of students.

Kulhavy, Schmid, and Walker (1977) compared two content structures in terms of two different kinds of test question. They found that what high school students remembered from a text was affected by both the content structure of the text and the kind of comprehension performance required. In other words, whether a text is assembled around semantic-conceptual headings or temporal-ordinal (rank-order) positionings, the organizational pattern can influence the way students respond to test questions. It was concluded that students provided with a semantic structural pattern were better able to group recalled ideas into semantic categories (e.g., conceptual headings) than into temporal categories (e.g., chronological order of presentation). In contrast, evidence suggested that students provided with temporal organizational patterns (emphasis on the serial ordering of events) were better able to group remembered concepts in a temporal fashion.

Relationships Between the Structure of Textual Content and Memory

Readability estimates are dependent on the current structure of the instructional materials and usually referenced in terms of varying forms of comprehension. The work of Corey (1977) and Kulhavy et al. (1977) represents a recent focus by many educators and psychologists on such structure in relation to comprehension (and theoretical memory structures). More specifically, those interested in psycholinguistics and cognitive psychology have produced during this decade an abundance of theoretical and experimental research papers describing how authors' structural patterns present in all textual materials can influence students' abilities to remember particular kinds of information.

One problem in science education is that most of the learning techniques used to facilitate reading comprehension (see Table 2) are based on teachers' commonsense notions and their experiences with similar material rather than on theoretically or empirically based studies. Therefore, a procedure is needed to identify reliably the content structure of a passage and an adequate theory of learning and memory to explain the functional relationships between content structure and student performances on comprehension tests.

Some science educators might contend that cognitive postulations of such theorists as Ausubel, Gagne, and Piaget in fact provide reasonable explanations of such relationships. Perhaps so. But more recent theoretical advances (e.g., schema theory) in content and memory structures represent mere extensions of those cognitive psychologists' works who dominate the science education literature (Anderson et al., 1977). Science educators interested in a comprehensive description of schema theory should consult works by Spiro (1977) and Rumelhart and Ortony (1977). More generally, Meyers (1977a, 1977b) discusses the effects of different content structures used by authors on students' test performances in terms of memory structures. Furthermore, she directly relates her descriptions to ways of improving the readability of school content materials.

Recent studies (see Meyers, 1977a) suggest that students reading textual materials must organize major and minor ideas in a logical fashion. Students remember textual information by either choosing the structure employed by the author or imposing a structure of their own. Apparently, storage of science content in memory can most efficiently be achieved by using the writer's structure (e.g., organizational strategies). Therefore, science writers should organize their instructional materials in a clear, unambiguous, and coherent fashion. Of course, students are not always in a position to capitalize on a writer's content structure, especially when author-student goals are in conflict. For example, the student's objective may be to scan the material for answers to specific questions or for an understanding of a particular idea. In such cases, students are forced to develop their own means of reorganizing the presented information and integrating this information into existing memory patterns or templates.

It is logical that such restructuring processes would more often be required in the study of science than in the study of a novel. Theoretically, authors describing independent concepts and their definitions should organize their writing in a "compartmentalized" fashion to permit the readers to learn and remember small portions of the total information. In contrast, authors describing broad principles and emphasizing conceptual interrelationships should use a "connective" style of writing. Accordingly, experimental research is needed to identify those content structural patterns best suited for different kinds of writer's objectives. The design used by Kulhavy et al. (1977) could be applied to this problem whereby two writing patterns describing the same information are evaluated using two analogous comprehension measures. For example, students could be randomly assigned to instructional treatments presenting the human nervous system and using either the compartmentalized style chosen by the authors of *Modern Biology* or the more connective style chosen by the authors of BSCS (Biological Sciences Curriculum Studies) textbooks. Theoretically, students exposed to a compartmentalized style would score well on a test requiring the matching of concept labels to their definitions or examples. In contrast, students exposed to a continuous style would score at a high level on a test evaluating main ideas or broad principles. Anderson's (1972) description of comprehension test questions is informative and often cited in work related to the structure of text and memory.

In conclusion, current ways of assessing and reducing the readability load of science materials are inadequate. Therefore, more theoretical and research work is clearly needed to help teachers in assessing the appropriateness of science materials and to assist students in comprehending explanations of sophisticated content.

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Science and the Physically Handicapped

Kenneth S. Ricker

Recent court decisions and federal legislation have proclaimed the rights of handicapped students to receive an appropriate public education in the least restrictive environment. More and more science teachers will be asked to make science courses accessible to handicapped students. The challenge to fully integrate physically (sensory and orthopedic) handicapped students into science classes creates a complex problem for science educators. There is no existing organized body of empirical data on teaching science to physically handicapped students that can be used to develop guidelines to initiate the integration process. There is a need to prepare teachers to handle the integration process, and there is a need to develop specialized materials and modifications for the instructional strategies generally used in teaching science. If these needs are not adequately resolved it will be extremely difficult to prepare physically handicapped students to be totally integrated into the adult world of the twenty-first century.

During the history of our nation we have experienced many diverse revolutions, or movements, against conditions existing in our society. Some have received extensive attention on a national, and even international, scale. But other revolutions have received much less attention—the so-called "quiet revolutions." The movement to establish the right of handicapped students to receive an appropriate education is an example of a quiet revolution.

For more than 200 years schools have continually denied handicapped students a free public school education in an appropriate educational environment. History usually shows that when such conditions continue to persist in our society the judicial system of our nation has become involved. In the past decade there have been numerous court decisions that pertain to the education of handicapped persons. These decisions have established the following principles (Turnbull, 1978):

Zero Reject—every handicapped child has a right to receive a free public education;

Appropriate Education—the handicapped child must receive an education meaningful to the child;

Least Restrictive Placement—the handicapped child must be educated alongside non-handicapped children to the maximum extent possible;

Nondiscriminatory Evaluation—the assessment of the handicapped child must be nondiscriminatory; and

Procedural Due Process—the handicapped child has the right to challenge the decisions made about his/her education.

State and federal legislation have also proclaimed the rights of handicapped students for an appropriate public education. At the federal level the most recent legislation, the Education for All Handicapped Children Act (PL 94-142) was passed in November 1975. This Act, referred to as the Bill of Rights for the Handicapped, encompasses many features of earlier legislation and clearly establishes a definite commitment on the federal level to become deeply involved in the education of the handicapped (Goodman, 1976). The law establishes the education of handicapped children in accordance with their needs and abilities as a fundamental right. For each handicapped student an Individualized Educational Program (IEP) must be written. The IEP is a diagnostic-prescriptive type educational plan which is to be developed jointly insofar as possible by the school personnel, parents and handicapped student.

In summary, the quiet revolution has reached its climax. It is no longer possible for it to remain a quiet revolution. Teachers, administrators and parents will become active in the implementation of these policies. Both sighs of anguish and sighs of relief will be heard in this struggle to achieve a quality education for all handicapped students.

The Handicapped Student

What is a handicapped student? A simplistic answer that one might suggest is that a handicapped student is unable to learn what is expected in a regular classroom in a manner that most of the students learn it. The handicapping factor becomes evident if a person is viewed as having the potential of being an information processing system that is able to think. A person has several sensory modes (the visual, auditory, olfacotry, gustatory and, skin senses) through which information is gathered. This information is interpreted and encoded. The acquisition of these interpretations (often called perceptions) enables the individual to learn how to perform thinking or cognitive tasks. While recognizing this as an over-simplified model, it does enable us to examine briefly the nature of being handicapped.

Being handicapped for some students means that they are unable to use one or more of the sensory modes to gather information. These students may have little difficulty in processing the information to form perceptions, but they must receive more information than the non-handicapped person needs before they can start to function. Other students may have perceptual handicaps. That is, these students are unable to process incoming information so that meaningful and lasting interpretations can be formed. Consequently, these students may encounter difficulties in learning to perform cognitive level tasks. Finally, there are students who are "cognitively" handicapped. For some unknown reason these students are unable to do higher level tasks even though they have no sensory or perceptual handicaps. For example, a student may be unable to retrieve information effectively and efficiently after it has been received, processed, and stored.

Educators should not become overly concerned with the basic causes of these handicaps. Educators should accept both the student and handicap, regardless of whether the cause of the handicap is physical, biochemical or developmental. Learning strategies should be used to permit handicapped students to achieve to the greatest possible degree. If this is not done, handicapped students will also become educationally handicapped.

Science and the Physically Handicapped

This paper is concerned only with teaching science to students who have sensory (auditory or visual) and orthopedic (crippling and mobility conditions) handicaps. Many students with these physical handicaps have not had full access to public school science programs, particularly beyond the middle school grades. The exclusion of students from appropriate science programs on the basis of these handicaps is unacceptable. Physically handicapped students should have the same access that non-handicapped students have to science programs. In addition, these handicapped students should receive similar encouragements and equal opportunities to pursue studies that will lead to science related careers.

Scientists and science educators have recognized the challenges of making science education and science related careers accessible to handicapped persons. Two professional organizations have been established recently to work toward the solutions of these challenges: Science for the Handicapped Association (SHA) and the Foundation for Science and the Handicapped. SHA was formally organized in March, 1977 at the national convention of the National Science Teachers Association. It was an outgrowth of informal meetings of science educators attending prior NSTA conventions. SHA is seeking to promote and advance the teaching of science, the development of curricula and instructional materials for students with any manner of handicap for learning. The Foundation was formally established in February, 1978 at the annual meeting of the American Association for the Advancement of Science (AAAS). This organization resulted from the efforts of a small group of concerned persons that included many handicapped scientists to have barrier-free meetings and to prohibit other unwarranted discrimination against handicapped persons. The Foundation's goals are focused on the involvement of handicapped scientists in all activities of the scientific community, particularly those of the AAAS and its affiliates; the development of quality science education programs for handicapped students; the elimination of barriers that deter students from studies leading to science related careers; and the employment opportunities for handicapped scientists.

Federal agencies also have become involved in science education for the handicapped. For example, in 1977 the Bureau of Education for the Handicapped, U. S. Office of Education, provided a grant to initiate the Science Activities for the

Visually Impaired (SAVI) Project at the Lawrence Hall of Science, University of California. This project is developing activities for middle school aged students to help them acquire logical thinking processes and basic science concepts. For each of the fiscal years of 1977 and 1978 the National Science Foundation has made approximately $500,000 available for projects dealing with physically handicapped students. These projects are supposed (a) to identify and provide information on the obstacles before the physically handicapped in becoming scientists and ways to overcome these problems, and (b) to develop student science training models directly involving handicapped students at secondary and college levels.

However, these efforts as well as the efforts of others, have barely jarred the door open to provide physically handicapped persons full access to science education. The remainder of this paper will discuss different aspects of the problem to illustrate the scope and complexity of some of the related concerns. Only if these concerns are adequately resolved will it be possible to prepare handicapped students to be totally integrated into the adult world of the twenty-first century.

Instructional Concerns

The basic concern in teaching physically handicapped students is the need to establish compatibility between the primary modalities by which the student acquires information and the modalities used in the instructional process. Science teaching has relied mostly on the visual (textbooks, films, demonstrations, etc.) and auditory (teacher talk) modalities with some use of the tactile (lab activities) modality. This instructional approach assumes all students can see, hear and touch equally well. What happens when an auditorily, orthopedically or visually handicapped student is placed into this system? The primary modalities by which a blind student learns may be touch and hearing, causing an incongruence between the regular instructional process and the way this student learns. Or if an orthopedically handicapped student is unable to handle materials he will be unable to perform any of the lab activities.

In cases of an incongruence it becomes necessary to modify the regular instructional process. For example, since the blind student will not be able to study the diagrams in the textbook on mitosis, an alternative strategy that uses the modalities of touch and hearing may be used. This alternative may be accomplished by using a raised schematic and audiotape that describes to the student what he sees with his hands as he explores the raised schematic. For a profoundly deaf student who relies heavily on reading the textbook and doing the lab activities another kind of modification may be required. So that this student has complete access to the auditory portion of the course (particularly the teacher talk and class discussions) it may be essential for the student to receive a copy of the teacher's notes as well as a copy of another student's notes. It is highly improbable that this auditorily handicapped student can read lips and take complete notes simultaneously, particularly in classrooms arranged in a theatre type manner.

There are two general kinds of instructional modifications. One kind requires highly specialized procedures, materials or aids to be used. For a profoundly deaf student, use of captioned science films or even an interpreter in the classroom may be required. (This latter situation poses an interesting problem. How easy will it be to locate an interpreter who can function efficiently and effectively in a science classroom where a highly technical vocabulary may be used?) The second kind of modification will not require highly specialized materials or procedures. For a profoundly deaf student it may mean using a different seating arrangement and the elimination of the teacher talking to the chalkboard.

The primary purpose for making modifications is to make regular science programs accessible to physically handicapped students. Attempts to develop special courses for these students should be viewed with extreme caution. Schools should not have courses such as Biology for the Blind, Deaf or Orthopedically Crippled. Neither should schools inaugurate separate sections of the regular science courses for handicapped students. Just because a student is handicapped is not an automatic excuse to expect him to do less than a non-handicapped student. Double standards should not be encouraged. It is not fair to the handicapped student, to the other students, to the parents, nor to society.

But what about having handicapped students in the science lab? This is a common concern of science teachers. Frequently, it is suggested that a student who cannot see or handle materials should not be allowed in a science lab. These students, they believe, should not be allowed to take the course or at least they should be exempt from the lab portion of the course. This is an unacceptable solution to the problem.

Assuming that the basic purpose of the laboratory is to help students understand the process of scientific inquiry, it is hard to justify automatic exclusion of physically handicapped students from the lab. This may mean that the role of the handicapped student in the lab should be defined differently. In addition, the physical arrangement of the lab may need to be altered. How, for example, may a quadriplegic student participate in lab activities? The lab station could be altered so that the wheelchair can be placed where the student can observe a lab partner. The student can participate mentally in the process of collecting data and analyzing them. In some cases this student could verbally direct a laboratory investigation. The fact that the student is unable to measure out specific quantities of chemicals and then mix them in a certain way is less important than the fact that the student knows what should be done, why it should be done, how it should be done and how to interpret the results.

For a visually handicapped student it could mean that the student should have a sighted lab partner for some activities. While a visually handicapped student may not be able to use a microscope he should know the kind of information that is collected by its use. He also can make "drawings" of what the sighted partner sees by using clay, string, glue and other such items.

In the development of alternative strategies great care must be exercised so that all students with the same handicap are not treated alike. It is impossible to develop a single strategy for teaching science to all students classified as having the same handicap. All students with visual handicaps do not function the same way in the classroom. The degree to which they rely on their tactile modality as a substitute for visual modality; the degree of visual memory they possess, if any; and how well they use any residual vision they have are examples of the factors that can affect the way a visually handicapped student functions in a learning situation. For these circumstances it is imperative that the instruction of handicapped students be based on intra-individual differences and not inter-individual differences. The use of the latter concept only places students with similar handicaps in the same group. This concept does not recognize the fact that all the students classified as having a given handicap do not function the same way in a learning situation. Understanding intra-individual differences recognizes that each student has both strengths and weaknesses. The instructional process should capitalize on the strengths of the individual as remedial help is provided to overcome weaknesses whenever possible.

Considerable attention should be given to the potential impact that modifications in instructional strategies could have on the dependence of handicapped students. There is concern that modifications of the instructional process could hinder the development of independence on the part of handicapped students. Handicapped students may become overly dependent on a system that is constantly modifying itself to accommodate their needs. In this kind of system how does the handicapped student gain the attitudes, skills, and practice to adjust to conditions outside the system in the real world which is much less accommodating?

Some persons support the idea that the acceptability of instructional modifications should be based partly on their effectiveness with non-handicapped students. A modification designed for use with a handicapped student should also be an effective instructional strategy for non-handicapped students. This notion of acceptability does not include those modifications unique to a certain handicap, such as the use of braille by a blind student. It does include such modifications as the use of microphotographs with visually handicapped students who cannot use a microscope but have some residual vision. To be an acceptable modification it should also be an effective strategy for use with non-visually handicapped students. Or if certain visual aids are used to help the vocabulary development of auditorily handicapped students it should also be an effective strategy with some students who are not auditorily handicapped.

Another concern regarding the necessity to modify the instructional process for handicapped students relates to the ability of individual school systems to accomplish it. Perhaps if every school system had unlimited financial and human resources this would not be a concern. Since this is not the case, it becomes a very realistic and important problem, particularly for small school districts. In small school districts the number of physically handicapped students will be very small and will fluctuate greatly over a period of time. State, or even regional, educational resource centers for teaching handicapped might be considered. These centers could coordinate the development, evaluation and dissemination of these modifications. In some cases the centers could serve as a lending library where a specific aid is needed for a limited amount of time. This would avoid the possibility of having a school district purchase an item that will be put on the shelf after it is used, waiting for another handicapped student to come along with a similar need. These centers could serve as a crisis-line for individual classroom teachers who come to school and hear the principal say, "You will have a new student in your biology class starting tomorrow. The student is orthopedically handicapped."

A final issue involving the modification of instruction deals with the financial aspects. It is not practical to consider developing modifications for every handicapped student on an individual basis. Rather, modifications should be developed that are generalizable to as many different kinds of situations as possible. The cost of a modification in terms of its effectiveness should also be considered. High priced modifications with limited use should be avoided whenever possible.

Teacher Education Concerns

The quality of science education that physically handicapped students receive will depend ultimately on the classroom teachers. The degree to which science teachers are sensitive to the needs of handicapped students and are able to translate this sensitivity into an appropriate course of action will be a crucial factor. The first step in this process must occur within the teachers. They must be able to accept the handicapped students into their classrooms as full-fledged members of the class. Teachers must be able to "see beyond" the handicapping conditions, and avoid becoming so emotionally involved that these handicapped students become either second-class student citizens or a step above first-class student citizenship.

Where and how do teachers acquire this awareness? What background information do science teachers need in order to plan science classes to include a deaf student, a blind student or an orthopedically handicapped student? How will science teachers acquire and practice skills for teaching handicapped students? For example, how will teachers be prepared to match handicapped students with the appropriate instructional process? The teacher must have an accurate assessment of the way a handicapped student functions in a classroom setting so he or she can identify an instructional process that is compatible with the way the student functions. Then the teacher must gather the appropriate materials so that this match between the student and instructional process can be implemented.

The preparation of science teachers to handle these situations is a severe challenge to teacher educators. Several approaches are now being tried in four-and five-year teacher preparation programs. It is too early to assess the effectiveness of these approaches.

One approach is based on the assumption that the notion of student normalcy upon which science methods classes have been based must be broadened. Science methods courses have not considered it normal for a teacher to have a blind student, a deaf student, or a quadriplegic student in a science class. Therefore, the content of methods courses have included very little, if anything, on the teaching of science to handicapped students. By accepting the idea that it will be normal to have these students in science classes, the preparation of teachers to work with handicapped students is included in the regular science methods course. This approach does raise the question of whether the instructors of science methods courses are adequately prepared to handle this broadened concept of student normalcy or heterogenity.

A second approach for the preparation of teachers involves the addition of another course to the teacher preparation program. This course is a general introductory course in special education which considers the identification and teaching of all exceptional students, not just handicapped students. The instructor of this course is usually a person trained in the field of special education but not in any specific subject matter area. This approach presents a problem for the preparation of subject matter teachers. The science teachers may receive no knowledge about or exposure to curriculum materials and teaching strategies unique for use in science classrooms.

A modification of this approach is used to help to overcome this problem. The course is divided into two parts, both being taught concurrently. One part is taught by a specialist in the field of special education and the second part is taught by a subject matter specialist. In this arrangement all teachers are together for the general and common aspects of the course, and then are separated into small groups on the basis of their teaching fields. This means that the science teachers work with a science education specialist on the unique aspects of teaching science to students with special learning needs. This modification appears feasible only for programs with a large teacher population and an adequate faculty.

A special education/science education methods course is also being tried as an alternative way to prepare teachers. The primary instructor for this course is a science education specialist. The course is open only to science teachers. This approach does necessitate having an instructor who is adequately prepared to handle both fields: special education and science education. By having a separate course the notion of student normalcy used in regular science methods courses is less affected.

Regardless of which approach is used to prepare teachers, some authorities suggest that every preparation program should include some field-based experiences with handicapped students. Many prospective teachers have never really had an opportunity to become aware of what it means to be handicapped in terms of being a student in science classes. To include a field experience in the program for every prospective teacher presents a problem. The number of handicapped students is extremely small in terms of the number of prospective teachers in teacher education programs, particularly in non-urban areas.

Perhaps all of these approaches may turn out to be ineffective. It might be more feasible to consider re-defining the role of special education teachers and the preparation of new kinds of science educators. Why not prepare special education/science resource teachers? These teachers would be specialists in teaching science to students with special learning needs. They would work closely with the science classroom teachers to help plan *and* implement an appropriate instructional process to meet the unique needs of individual students. This would include the needs of all exceptional students, not just the physically handicapped. Support for this kind of approach may come from those who feel it is nearly impossible to adequately prepare a prospective science teacher in science subject matter, teaching methodology, and also in many aspects of special education. Further, even if it is possible to achieve a minimum level of acceptable preparation, it will be impossible for the science teacher to keep abreast of new developments in all these areas while maintaining a full time teaching position. Some persons may also suggest that it will be nearly impossible to prepare a special education teacher to function as an effective resource teacher for all the subject matter teachers in a school system. Therefore, special education teachers should concentrate on teaching in specific subject areas.

At the present time it is not possible to predict which approach, or approaches, will be effective for teacher preparation programs, and under what conditions. Only when the research concerns, which are presented next, are sufficiently studied will it be possible to identify solutions to many of the instructional and teacher education concerns.

Research Concerns

There is one basic research concern regarding science education and the physically handicapped. Simply stated, very few empirical studies have been made of teaching science to handicapped students. In addition, what little research literature that does exist has not been analyzed critically in an attempt to conceptualize the results and compare them with the research findings in other areas. With the absence of empirical data, decisions on teaching science to handicapped students are being made on intuition or trial and error techniques.

The development of a variety of research trusts will necessitate the emergence of a "new" kind of researcher or research team: a special education/science education researcher or team. Presently there are virtually no science education researchers who also have research expertise in the field of special education, nor are there special education researchers who have research expertise in science education.

It will be increasingly important that alternative or new research techniques be used. For example, in many studies with handicapped students research techniques that are effective with very low *n* samples will be essential; and the development and validation of evaluation instrumentation that eliminates any bias toward handicapping conditions will be necessary.

As basic research thrusts are initiated researchers should avoid a common error of many science education research thrusts of the last two decades. Too many research studies have failed to investigate the experimental effects over a long period of time. Few systematic attempts have been made to collect longitudinal data. Educators must be concerned with both the short- and long-term effects that a specific program, instructional process, or educational environment has on the education of students. Effects which appear to be immediately beneficial to a handicapped student may turn out to be detrimental over a longer period of time.

Research efforts dealing with physically handicapped students may provide new insights on the way non-handicapped students learn. Suppose a researcher considers the question, Does the primary modality by which a student gathers knowledge about his physical world affect the way he internalizes the knowledge or structures the knowledge in his mind? For the past two decades a key phrase in science teaching has been "hands-on" activities. Does a quadriplegic student who never manipulates any materials in science class internalize knowledge in a way different than a student who is able to handle all the materials?

As researchers examine the characteristics of teachers who work well with students with handicaps it may help reveal more precisely those teacher characteristics that are essential to work with non-handicapped students. Or the results of such studies may promote the concept that teachers who possess certain characteristics should be placed with students who have certain dominant learning styles.

While it is imperative that research studies be conducted with only handicapped students, it is equally important that researchers consider the inclusion of relevant hypotheses in research studies that will use a population that includes handicapped students. This inclusion of mixed classes will become increasingly possible as more physically handicapped students receive their education alongside non-handicapped students.

Conclusion

By the arrival of the year 2000 we may hope that the need to write an article on science education and the physically handicapped will no longer exist. Science classes should be completely accessible to all students for whom they are appropriate. Similarly, there should no longer be a need to focus attention on women or minorities in science. Rather, appropriate and quality science education would be available for every student—regardless of the modality (or modalities) by which the student functions, the student's sex or ethnic origin, the student's aptitude or learning style. Perhaps, a plan such as the Individualized Educational Program (IEP) presently mandated for handicapped students will be normal for all students. If the education of students has not reached this status in the country, by the twenty-first century, another public law that will parallel our present PL 94-142, the Education of All Handicapped Children, may be necessary: PL 106-142, The Education of ALL Children.

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Integrated and Functional Science Preparation of the Elementary Education Major: A Model

Hans O. Andersen

Elementary school teachers frequently are criticized by scientists and science educators for not doing something they were never prepared to do—teach science in the elementary school. The purpose of this article is to describe the evolutionary development and installation of a program model that has as its prime objective preparing elementary teachers who will involve students in science learning activities on a regular and continuing basis. The model incorporates principles of relevant content selection, appropriate practice through early and continuous experience, basic skill remediation, and integrated, unified, or holistic science with a continuous effort to relate the science that the elementary education major is learning to the future role as elementary school teacher.

The purpose of this article is to describe a model for the science preparation of the elementary school teacher, and the action that was involved in preparation for its implementation. The model was developed to prepare elementary school teachers who will recognize the significance of science and who will, on a regular and continuing basis, involve their students in learning science. The model incorporates principles of relevant content selection, appropriate practice through early and continuous experience, basic skill remediation, and integrated, unified, or holistic science with a continuous effort to relate the science that the elementary major is learning to his or her future role as an elementary school teacher.

Readers of this article most likely will conclude that its designation as a science model is inappropriate, since the commonsense principles that compose the model are certainly not uniquely science. However, for reasons to be explained, specific and rigorous attention to the science preparation of prospective elementary school teachers is particularly essential today.

The Almost-Myth of General Education and the Elementary Teacher

College catalogs, academic advisers, and college professors frequently begin the examination of college education with a discussion and explanation of what the term "General Education" means at their institutions. It is frequently safer to attack motherhood and apple pie than to attack the general education requirement. The intent here is not to attack the idea of general education. The author shares the conviction of many colleagues that a person achieving a "general education" will be a better teacher. He also shares a conviction with most colleagues that a general education cannot be achieved by most students within the confines of a four-year college curriculum. It would be much more appropriate to involve students in exploring what is meant by the term "general education," building a rationale for its pursuit and establishing general education as the student's lifelong educational goal, than it is to continue pretending that a general education can be achieved so easily.

Developing in students an appreciation for general education should be an attainable goal. In fact, developing this appreciation should be accomplishable in much less time than is traditionally allocated to general education, which, according to James's Law of conservation (Lord James of Rusholme, 1977) of the curriculum, is essential. James's Law states: "Whenever you add anything fresh to the curriculum you must inevitably take something out, and state honestly what it is and why it is being removed." Here are some facts—at least, here are some factually-derived opinions shared by many persons who support the claim that *general education science courses* should be eliminated from the elementary major's program because they have not in the past and will not at this time prepare teachers who will in fact teach science on a continuous basis in the elementary school.

1. General Education is required--but
    a. It is probably impossible, given the fact that the quantity of knowledge continues to expand, given our student population, and given a 70-credit-hour limit, to provide a good general education to the elementary education major.
    b. Elementary teachers who have completed a general education science sequence have not been teaching science.
    c. Elementary teachers completing a general education science sequence have not pursued additional education in science.

Therefore: General Education requirements are not successfully serving the preservice elementary major.

2. We teach what we have learned!
    a. Because science is rarely taught in the elementary school, the elementary major did not learn elementary science while an elementary pupil.
    b. The purpose of high school science is to prepare students for college science, which is generally up-to-date modern science.

c. The purpose of general education science courses is usually to introduce the student to the nature of the field today and not to science in the elementary school curricula.

Therefore: The elementary major will not have learned elementary school science and therefore will not be prepared to teach it.

3. We all tend to teach as we were taught!
   a. Science, when it is taught in the elementary school, is often taught as a textbook subject.
   b. High school and introductory college courses are frequently (and in the case of the college *most* frequently) taught as a rhetoric of conclusions.

Therefore: Elementary teachers, if they teach science, will teach it as a textbook subject or as a rhetoric of conclusions.

One may hope that the reader is now ready to conclude that the typical general education science requirements are not providing what today's elementary major needs. Perhaps at some future date when the elementary major learns elementary science as an elementary pupil it will be possible and desirable to pursue general education types of science courses. At present, one is hard-pressed to avoid the conclusions that elementary majors must be taught what they will need to teach (and what they did not learn) in a manner consistent with how they should teach that science.

Toward a Coherent Model

Indiana University has always had science faculty who were interested in the problems of elementary school teachers. These faculty members developed and offered courses with emphases that were useful to the prospective elementary school teacher. However excellent, their efforts were futile because all of the students could not be scheduled into their courses, and isolated courses rarely provide the articulated program these students need. Motivation for developing an articulated program simply did not exist. A revision of Teacher Certification Guidelines provided the necessary impetus. The following quotations from the certification document in particular stimulated the kind of thinking that convinced the faculty that a program was necessary.

> This area shall be designed to develop *broad functional understandings* of *conservation* and the *physical*, *biological* and *earth* sciences. An integrative approach shall be used whenever possible.
>
> The professional component shall begin early in the student's educational career. Laboratory experiences shall be initiated as soon as possible and continued throughout the student's program of preparation. (p. 18)

A planning team consisting of scientists and science educators was formed to discuss how the Department of Science Education at Indiana University would satisfy the changes mandated by the state document *TEACH*.[1] The faculty began deliberations with a discussion of what was needed and what was already being done. It was pleasant to discover that there was already successful experimentation with elements of what might become a new and much improved program. What became increasingly obvious was the fact that if we wished to put together a program consistent with stipulated descriptions provided in *TEACH*, then considerable effort and possibly external funding was needed. We began pursuing external funding which, as usual, demanded a clear statement of the problem and some *viable* ideas that potentially could become solutions to the problem. We identified three types of problems—student-need problems, state-of-the-art problems, and institutional problems.

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[1] Teacher Education and Certification Handbook (1978)

Student-Need Problems (Preservice Elementary Majors)

1. The students' backgrounds and abilities are extremely diverse.
2. Most students cannot perform the science process skills.
3. Most students do not understand or think they do not understand the science content in existing elementary curricula.
4. Most students do not perceive their college science courses to be useful to them as elementary school teachers.
5. Most students do not relate the science they are learning to science lessons they may use as teachers.

State-of-the-Art Problems

There simply is not enough knowledge about designing and implementing a science program that would provide for the preservice elementary teacher a *broad functional understanding of science* within the limits established. Furthermore, developing definitions for the terms *broad functional understanding* will take considerable effort.

Institutional Problem

The courses that evolve must satisfy criteria of the departmental and college curriculum committees. The essential dilemma arises from the state's demand for courses that will provide this population of students with a *broad functional understanding*. *Functional* implies that what they learn will be useful! The most and perhaps only science that would be specifically (uniquely) useful to an elementary teacher is the science he or she must teach. The fact that the typical elementary teacher does not understand the science he or she is to teach also tends to make the teaching of this science more important—more *functional*. Needless to say, it would be enjoyable to teach the elementary majors the science they might need in five or ten years or the science they will need to work with the brightest children. However, there are prerequisites! Today's necessity should be teaching the future elementary teachers what they need today. Later we may design inservice opportunities for practicing teachers to get them where we think they belong!

The first question became, "How will we convince curriculum committees to consider this unique population and its unique needs for a *broad functional understanding of science*?" Then the essential question became, "Where will we get the money to fund the necessary planning development effort?" Seed money was provided by the Office of the Dean of Learning Resources.[2] This money was used to develop a model and prepare a proposal that was submitted to The National Science Foundation. Development proceeded under NSF funding.[3]

The Indiana Model

The diagram of the model (see Figure 1) is an attempt to illustrate that the mandated broad functional understanding of science will be developed by providing students a program that integrates or unifies the teaching of science concepts/processes with planning/teaching strategies and practice in teaching science.

Note, there are three confluent streams—Content/Process, Planning, and Practice. The first course in the Content/Process Stream is entitled *Basic Science Skills*. This variable credit course is taught by education faculty. The purpose of this course is to prepare students for the science sequence. Two facets will be examined by pretest: (a) the science-process skills and (b) skills specified as being requisite to the next science courses. Students with adequate background may test out of this course, or portions of the course. Other science courses in this sequence include four-credit-hour biology and physical science courses and two-credit-hour earth science and astronomy courses. This arrangement is used because it is most consistent with the organization of Indiana University. Content selection for these courses will be described later.

The Planning Stream consists of three one-hour methods courses that are taken concurrently with the named science course. The purpose of these methods courses is to provide students with an opportunity to plan to teach elementary-age children the science they, as college students, are learning in the science education classes.

The Practice Stream flows directly from the methods course of which it is really a portion. Its purpose is to provide the preservice teacher with hierarchically sequenced practice opportunities. Specific course descriptions follow.

Q200 Basic Science Skills (3 credit hours)

> Provides the elementary education major with necessary background in the science process skills to successfully complete other science courses in the sequence.

Q201 Biological Science for Elementary Teachers (4 credit hours)

> An introduction to the principles and practice of biology designed especially for prospective elementary education teachers. All major areas of biology will be considered, with a concluding emphasis upon the relations between various organisms and their environment.

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[2] This is an all University office that stimulates the development of all learning resources on all campuses of Indiana University.

[3] NSF SER 76-81175 Andersen—Science preparation for prospective elementary teachers, June, 1977 through May, 1979.

Q211 Elementary Science Methods One: Emphasis—Biological Science (1 credit hour)

The focus of this course is the teaching of biological science processes and concepts in the elementary school. Activities include writing performance objectives, lesson planning, and the development of additional teacher competencies. Science processes and lessons will be explored through field experiences and will be related to work in Q201.

Q202 Physical Science for Elementary Teachers (4 credit hours)

Understanding of ideas and techniques needed for teaching physics in elementary school. Emphasis on tangible phenomena. Topics include motion, light, electricity, states of matter, energy, chemical reactions. Laboratory experiments based on materials used in elementary schools. Two lectures and two 1½ hour laboratories each week. Not open to students who have completed a college-level physics course. Does not count toward divisional distribution requirement.

Q212 Elementary Science Methods Two: Emphasis—Physical Science (1 credit hour)

The focus of this course is the teaching of physical science processes and concepts in the elementary school. Activities include writing performance objectives, lesson planning, and the development of additional teacher competencies. Science processes and lessons will be explored through frequent field experiences and will be related to work in Q202.

Q203 Earth Science for Elementary Teachers (2 credit hours)

Introductory course for majors in elementary education. Origin, composition, and structure of the lithosphere, hydrosphere and atmosphere. Interaction among spheres. Surficial processes with special emphasis on subjects commonly taught in elementary school. One lecture and one laboratory each week. Credit available only to students majoring in elementary education.

Q204 Astronomy for Elementary Teachers (2 credit hours)

Introduction to the sky, the earth as a planet, the solar system, stars, the milky way, galaxies, the universe, and additional topics in modern astronomy. Designed specifically to provide elementary education majors with an astronomy background and aid in the teaching of basic astronomical processes and concepts in the elementary school.

Q213 Elementary Science Methods Three: Emphasis—Earth Science & Astronomy (1 credit hour)

The focus of this course is the teaching of earth science and astronomical concepts and processes in the elementary school. Activities include writing performance objectives, lesson planning, and the development of additional teacher competencies. Science processes and lessons will be explored through extensive field experiences and will be related to Q203 and Q204.

The course descriptions provide some insight into the Indiana University program. They illustrate how business gets done. The real nature of the program is better described by the statement of "Our Beliefs" prepared by the author, revised with team input, and sometimes not too affectionately referred to as "Our Liturgy."

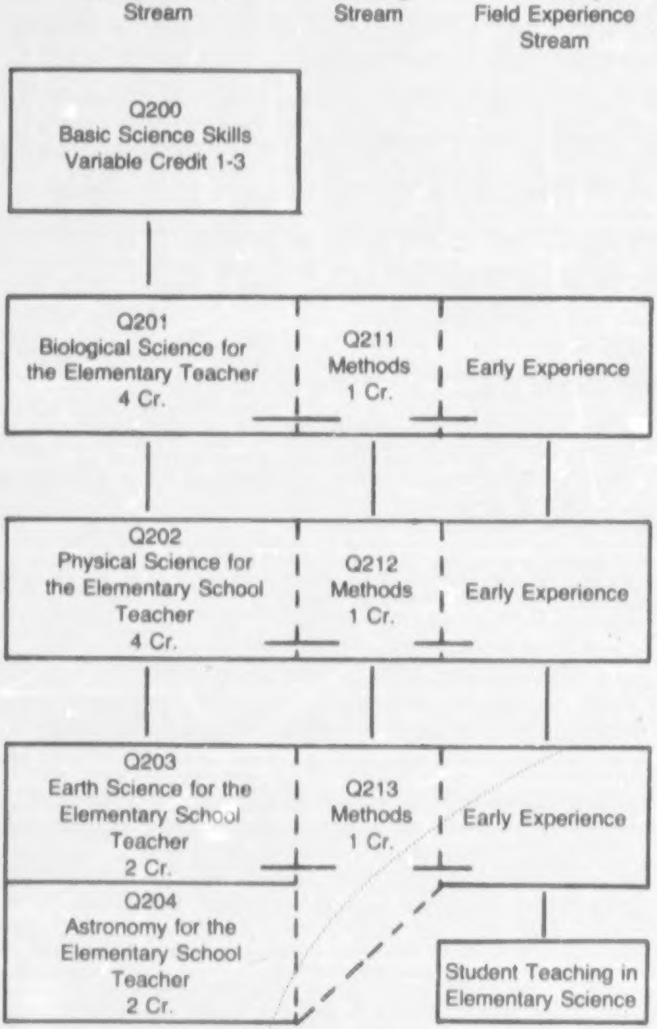
Content/Process Stream
Planning Stream
Practicing Field Experience Stream
Q200
Basic Science Skills
Variable Credit 1-3
Q201
Biological Science for the Elementary Teacher
4 Cr.
Q211
Methods
1 Cr.
Early Experience
Q202
Physical Science for the Elementary School Teacher
4 Cr.
Q212
Methods
1 Cr.
Early Experience
Q203
Earth Science for the Elementary School Teacher
2 Cr.
Q213
Methods
1 Cr.
Early Experience
Q204
Astronomy for the Elementary School Teacher
2 Cr.
Student Teaching in Elementary Science

Figure 1. The Indiana Model.

"Our Beliefs"

Obviously, it is time for a curriculum revolution, and that is the purpose of the project. The purpose is *not* to provide students with a general education in science. *The first purpose is to prepare teachers who will teach science in the* *elementary schools.* The first goal is professional. That does not mean that the faculty has given up the goal of preparing the *ideal* generally-educated elementary teacher. In fact, they believe that the elementary teacher who teaches science will, with increased frequency, discover its value and become a student of science and thereby attain what would be considered a general education in science. *Hence, the second goal is to prepare teachers who will continue to study science.*

More specifically, here is what we believe and what we plan to do about it as we redesign the curriculum for the science preparation of the preservice elementary teacher.

1. Because teachers are extremely busy they are forced to select science lessons from textbooks and curriculum materials that are most accessible.

   Therefore, we will give major impetus to designing experiences that will prepare preservice teachers to implement existing curricular materials.

2. There are easily accessible science lessons unique to our geographic location that are not, but should be, emphasized in the elementary curricula.

   Therefore, we will give major impetus to designing experiences that will prepare the preservice teacher to take advantage of the local setting to teach science.

3. The elementary teacher who understands the processes used by scientists as they do science will be a more effective science teacher.

   Therefore, we will formally introduce the preservice teacher to the science process skills and emphasize these skills throughout the sequence.

4. The preservice teacher needs to visualize the relationship between the science being learned and the future role as elementary teacher.

   Therefore, we will provide planning and teaching opportunities for the preservice teacher in which the teacher will plan and then teach the science he or she is learning.

5. For reasons beyond our control, and often beyond the student's control, many of our students are functionally illiterate in science. Because of basic skill deficiencies and the level of intellectual development, the students have been unable to learn science at anything other than the rote-memory level.

   Therefore, we shall attempt to individually remediate these deficiencies by providing basic skill instruction whenever it is necessary.

6. The sequence of courses in the science sequence should emphasize central themes and develop broad understandings.

   Therefore, as we review course outlines and develop instructional materials we will incorporate opportunities for students to visualize the central themes and develop the broad understandings.

7. Science courses should, to the extent possible, be integrated, to permit maximum necessary redundancy and minimum unnecessary redundancy. At

> the same time we recognize the value of the self-sufficient course to the student transferring into the program.
>
> Therefore, we shall attempt to compromise the integrated structure and the concept of course self-sufficiency to a point most beneficial to our students.

Basically, we believe that the traditional preparation programs have not been successful because they have failed to prove three thrusts in sufficient quantity:

Purpose—a reason for doing it,

Practice—to become skillful, and

Pride—a feeling of success.

We shall attempt to provide these aspects in our program.

Formalizing "Our Beliefs" in written form appeared to be a useful exercise. It established a tone and helped to clarify our purpose as team members. It also created a need to develop a list of the broad understandings and the themes we would use as achievement standards for our students and organizers for our work. Preparing a consensus statement of the broad understandings we hoped to develop was relatively easy. They are very similar to the "Major Items in the Process of Science," developed by the NSTA Curriculum Committee (1964).

Broad Understandings

1. Science assumes that the universe is not capricious.
2. Science is based on observation and measurement.
3. Science is an incomplete enterprise.
4. Science is an ongoing, continually correcting study in which models are constructed and refined or discarded in favor of more accurate precise models.
5. Science strives to improve measurement and continually attempts to estimate the magnitude of error in its measurement.
6. Science is a long range activity in which model building and refinement may take years.

Attaining consensus on the themes that would receive greatest emphasis and their wording was reminiscent of the conflict generated over *Theory into Action* (Ausubel, 1964; Glass, 1965). This list has stimulated continuing discussion that, quite honestly, is perhaps the single best reason for attempting to generate such a list.

Themes[4]

1. Energy cannot be created or destroyed but can be transformed into different forms for utilization.
2. Forces are the bases for the interaction of matter.

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[4] This draft of the Themes (about the 15th) was prepared by Dr. Judy Franz, the Physics member of the planning team.

3. Changes in matter with time, which may occur at different rates and in various patterns, are a result of interactions.
4. A change in one property of a system may cause alteration in other aspects of that system.
5. Energy from outside a system is needed to maintain the organization within a system.
6. All matter is composed of particles called atoms.
7. Nature can be described in quantitative as well as qualitative terms.

In closing this description of the Indiana Model, it is essential to state its most important ingredient—People. People who care about other people. People who love science! People who believe that everyone needs a functional understanding of science! People who believe that an accurate definition of teaching is *causing learning!* We have those people, and to them I credit the development of the Indiana Model for the Science Preparation of the Preservice Elementary Teacher.[5]

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[5] John Droste, geology; Judy Franz, physics; Hollis Johnson, astronomy; Albert Ruesink, biology; Dorothy Gabel, education; Albert Strickland, education; James Weigand, education; Harold Harty, education; and Hans Andersen, education.

Closing the Gap Between Research and Practice

J. Dudley Herron

Research says many things to the teacher. Among the generalizations supported by research are that people learn more when they are interested, and that they generally are more interested if the environment is pleasant and things make sense. Additionally, being able to make sense out of information depends on prior learning, intellectual development and the way material is organized; e.g., a "logical" development of science may be incomprehensible to beginners. Research also says that things that are taught are usually learned better than things that are not, and some of the things that are not taught seem to be very important; that individuals also learn more when they know what they are expected to learn and when they get good feedback concerning progress. Finally, research says that how material is packaged appears to be less important than what goes inside the package.

Practitioners in elementary and secondary schools have always looked upon research with a jaundiced eye. What does not look trivial or downright inane, seems to be impractical and out of touch with the realities of the classroom. To some extent, such skepticism has been deserved. Still, it would be just as wrong to suggest that research has nothing to say as it is wrong to suggest that research provides the final answer to all issues that concern teachers.

The complexity of teaching and schools makes it impossible to summarize in one place what research says to teachers. After all, there is research on classroom organization, motivation, attitudes, curriculum innovations, intellectual development and non-development, school finance, individualized instruction and self-pacing, cognitive style, classroom interaction, kinds and amount of teacher training, national assessments of educational progress, declining science enrollments, and declining scores on the SAT. The research emanates from a number of sources, is directed toward countless targets, and is influenced by ulterior motives and political machinations as well as detached scholarship.

Compounding the problem of great diversity is the fact that few studies are truly definitive. Rare is the study that "proves" one practice is superior to another or that the latest innovation represents "improvement." It is the rule rather than the exception that there will be several studies pertaining to an issue with at least one in the group appearing to contradict the results of another. Without careful examination of the studies, it is impossible to reconcile apparent contradictions.

This paper deals with generalizations based on an examination of many studies over several years. Where studies are cited, they are representative of what this author considers to be the preponderant view. They are not, in themselves, definitive.

The paper is limited to studies that might cast light on the teachers' lament, What can be done to make students learn?

Attitudes and Interest

Every teacher knows that attitude is important.

1. People who do not want to learn usually do not; people who do want to learn, may. There are important points to remember about attitude. One point was brought home several years ago during dinner. The author's older son, Keith, remarked as he put Worcestershire sauce on his meat, "I love Worcestershire sauce. I wish the oceans were filled with Worcestershire sauce!"

"Oh? How many bottles of Worcestershire sauce do you think it would take to fill the oceans?" the author replied.

For the next 45 minutes we ate and figured. We estimated the percentage of the earth's surface covered by oceans. We estimated the average depth of the oceans. We calculated the surface of the earth in square miles, the volume of the oceans in cubic miles, converted cubic miles to cubic feet, and cubic feet to gallons. From gallons we got quarts and from quarts we got ounces, and finally, bottles of Worcestershire sauce. Just as we triumphantly announced our estimate, his mother rose angrily from the table and shouted, "Who *cares* how many bottles of Worcestershire sauce would fill the oceans!"

The reaction was stunning. It had been a wonderful intellectual game, and we were proud that we had worked through it. To her it had been 45 minutes of boring trivia, and she was angry that we had wasted our time and hers.

The point is that what interests one intelligent person does not necessarily interest another. Because of differences in student characteristics, teacher characteristics, and interests, it is probably wise to incorporate a variety of approaches in the classroom. What is most interesting and effective for one student may be ineffective for another (cf. Cronbach & Snow, 1977).

Informal observation (rather than carefully controlled research) during the field trial of the *Intermediate Science Curriculum Study* (ISCS) supports this notion. ISCS is laboratory oriented. We know that junior high students are a virtual beehive of activity. They thrill at seeing bubbles and pretty colors and doing things with their hands. In ISCS, they have that opportunity. A teacher may be genuinely surprised when students ask, "Why do we have to work in the *lab* all the time?"

It is not just variety that makes things interesting. There is strong evidence that people are naturally curious and prefer to be mentally involved. Berlyne (1954a, 1954b) has shown that asking questions of students stimulates more interest than simply presenting facts. It also leads to improved learning. All of this suggests that:

2. When placed in a stimulating environment with enthusiastic people, some who think they do not want to learn, change their minds; and

3. Given a choice, people avoid unpleasant experiences and are attracted to pleasant ones. Children who know they are in for a spanking or tongue lashing take more time getting home than those who expect a banana split. Students who find their studies fun get to them sooner than those who find them drudgery.

These rather obvious statements seem to take on more importance in light of the 10th Annual Gallup Poll of Education (Gallup, 1978). Respondents were asked, "What subjects that you studied or experiences that you gained in high school have you found to be most useful in later life?" Science was seventh out of ten items—behind commercial subjects, such as typing and bookkeeping (third); shop courses (fifth); and extracurricular activities (fourth). When asked, ". . . [A]re there any subjects you wish you had studied and didn't that would be of special help to you now," the respondents listed science in fifth place, ahead of English and history, which are required in most schools, but behind typing, mathematics, shop, and foreign languages. Science is obviously not seen as the most useful or interesting subject offered in school.

Another factor in making learning pleasant is a sense of accomplishment. Nobody enjoys failure; everybody loves success. Science has the reputation of being difficult. Why?

It is quite likely that many students in physical science courses have not developed the logical operations that characterize Piaget's level of formal operations. Analysis of the content of these courses suggests that these logical operations are important for understanding the material (cf., Herron, 1975, 1978). Consequently, many students find it almost impossible to understand what is presented, and frustration and lack of interest are almost sure to follow.

It is quite possible that differences in intellectual development explain the relatively poor attitude of low ability students in Nuffield chemistry curriculum.[1] Kempa and Dube (1974) suggest that the "discovery, problem-solving" nature of Nuffield was less satisfying to low ability students than was the "fact-oriented" non-Nuffield syllabus.

It should be pointed out that whereas success is important, success alone may not be enough. Bandura (1977) has described a theory of "self-efficacy" which suggests that the student's interpretation of information determines its effect. If a student attributes success on an exam to luck rather than ability and effort, success may not lead to greater interest or achievement in the future.

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[1] A British chemistry curriculum funded by the Nuffield Foundation

Somewhere we got into the habit of making students feel stupid when they encounter difficulty in science. There is a certain elitism among scientists and science educators that contributes little toward improving our tarnished public image. There is at least some evidence that we could improve our image by helping students set reasonable standards for themselves and be realistic about the relationship between failure and lack of effort. Fear of failure is a major reason that students do not take elective courses such as physics (Lawrence, 1974; Spruung, 1974).

McKeachie reports a study by Heckhausen (1974) showing "that students who fear failure improved in performance when they were helped to attribute failure to lack of effort rather than to lack of ability and to set reasonable standards for themselves" (McKeachie, 1978, p. 326).

Factors that Affect Understanding

We have seen that understanding has an important influence on student attitude. It is, of course, important in itself. We would not be teaching if we did not want students to understand.

We have mentioned that level of intellectual development affects understanding. This variable is so important and Piaget's notions of intellectual development are so popular among science educators, that another article in this issue (p. 24) is devoted exclusively to this question. We focus here on other factors.

4. What appears to be the best way to organize information after someone understands it may not be the best way to organize information for someone who does not understand it. Authors and teachers are prone to sequence ideas in a logical order and it has been pointed out that logical order and psychological order do not necessarily coincide (Ausubel, 1963).

Evidence related to child development, learning, and intellectual development all suggest that learning occurs from the near to the far; from what is close to personal experience to what is further removed.

Logically, one may argue that the science curriculum in the secondary schools is inverted—that physics should be taught first, chemistry second, and biology last. Certainly physic concepts are used in chemistry and chemistry concepts are used in biology but not the other way about. However, even though it may seem logical to invert the normal sequence, Ausubel makes a convincing argument that the present order is correct.

From birth on we are confronted with observations of living organisms. We are living organisms. We certainly know something about ourselves. We do not have to be told that respiration is necessary for life. When we hear about the digestive system, circulatory system, or reproductive system, we already have numerous observations on which to build. One can scarcely live without knowing something about flowers and seeds and growing plants and plant cycles. Although one may argue that chemical reactions are involved in all of these changes, the nature of those changes is far less obvious. Still further removed from direct experience are the regularities in mechanical motion, heat transfer, and electromagnetic interactions that are the subject of physics.

Within courses we encounter the same kind of sequencing problem. Pick up and examine any introductory chemistry text. Is it organized according to a logical order or a psychological order? Does it begin with phenomena that are closely related to the experience of students? Does it introduce abstractions, for example, atoms, molecules, ideal gases, bonding, and kinetic theory only when the student senses a need for some way to explain what he has already observed?

More likely it is developed logically. First some tools: the metric system, temperature scales (all of them), perhaps some chemical symbols and a few equations, some math skills and significant digits, atoms in all of their glory, molecules, and bonding. This takes time but it certainly seems worthwhile because, once it is done, it is much easier to talk intelligently about chemical changes that we want students to see and to know.

The problem is that students cannot see where the sequence is leading, and it does not seem at all logical to them. We must constantly keep in mind that what appears to be a logical development to the teacher or textbook author who has studied a subject for years, may not seem logical to the student. The argument is not that subjects should be developed illogically; rather, it is that we should keep viewing our subject from our students' point of view and sequence the material in a manner that is sensible to *them*.

5. We are more likely to learn things that are taught rather than things that are not taught. When PSSC physics, CHEM Study, CBA chemistry, and other new curricula were introduced in the 1960's, everyone was interested in knowing how good they were. To find out, standardized tests such as the Cooperative Physics Text or the ACS Chemistry Test were given to students taking the new and old curricula (cf. Hipsher, 1961; Heath & Stickell, 1963; Rainey, 1964). Students in traditional curricula did better. This is not too surprising since the tests were designed for the traditional curricula and tested for what was typically taught in those courses. When tests designed for the new curricula were given, students in the new curricula did better. The results seem to say that we are more likely to learn what we are taught. (They also suggest that curriculum reforms designed to introduce something new usually leave out something old. We ought to be sure we are ready to give it up.)

There is a more important point to be made about not learning what is not taught. We complain that students are poor at solving problems but we devote little attention to teaching students how to solve problems. The attention that we do give is of the wrong kind.

Katona's (1940) work on problem solving has shown that the least effective strategy for teaching students to solve problems is to work examples for the learner—the strategy typically used in science classes. Focusing the learner's attention on the various principles that might be followed to solve problems of a given type is considerably more effective. Still more effective is what Katona called "learning by help." In this strategy, the instructor uses illustrations or examples to give cues to the student. The student is not told what to do to solve the problem but through the cues his attention is clearly focused on principles that must be considered in solving the problem. The.student has to "discover" the solution to the problem himself or herself—albeit, not without help.

Other research indicates that students are aided in problem solving when the instructor habitually "thinks aloud" as he or she is solving problems so that the student can see the strategies that are being followed (Whimbey, 1977). (Note that it is the *strategy* that the student needs to see rather than the solution.) Students also are encouraged to "think aloud" so that their strategies are apparent and cues can be given that lead them to discover errors in their thinking.

There are many other things that we do not teach. We seldom make deliberate efforts to teach laboratory skills that, much to our chagrin, students have never learned. We worry that students cannot interpret charts and graphs but we seldom stop to explain them carefully. We tend to assume that students see the same water molecule in a formula, in a ball-and-stick model, in a picture in a text and in a space-filled model tumbling across a movie screen. It is not necessarily so.

6. It is easier to learn something that somebody else wants us to learn when we are perfectly clear about what is to be learned. A lot has been said about behavioral objectives (cf. Baker, 1969; Duchastel & Merrill, 1973; Gleit & Ellington, 1978; Herron, 1971; Kibler, et al., 1970). Opinion is divided on their value and the research is not convincing that giving your students explicit statements of objectives will help them learn. However, research does suggest that students need to know what is expected of them.

In a course that provides frequent quizzes, carefully structured learning activities, and frequent verbal reminders of important points, written lists of objectives do not seem to matter. They are redundant. However, in courses that are loosely organized, where students have considerable freedom to learn as they choose, and where little regular feedback is given, lists of objectives usually prove to be important.

Research by Rothkopf (1971), Frase (1970), Morton Säljö (1976a, 1976b), and others indicates that questions interspersed in the text can be effective in guiding instruction. The general procedure is to ask one or two questions after two or three pages of text. These questions help students recall information of the *type* asked in the question, not just the specific information called for. For example, when the questions call for a numerical quantity or a proper name, other numerical quantities and proper names are selectively recalled. When questions call a technical term, this sort of information is selectively recalled. The questions appear to tell students what is considered important and what they should remember. Questions requiring synthesis of ideas appear to help more than those calling for recall of facts.

7. Learning is more efficient when you get frequent, unambiguous feedback concerning progress. Perhaps no other statement is better supported by theory and research. Virtually every learning theory emphasizes the importance of knowledge of results and common experience conveys the same message.

McKeachie (1978) points out that practice is important in learning only if learners see the results of their practice and get feedback that suggests how they might alter their behavior. This was amply demonstrated in a study conducted several years ago by this author and others (Herron et al., 1976).

In a study of concept learning, one group of students received a great deal of practice involving examples of a new concept but received no feedback which would tell them the characteristics of the example that made it a member of the class. The practice produced virtually no learning.

Concepts make up much of what we teach in science courses. By concept we mean a class of entities with common characteristics rather than the broader meaning given to the term in everyday speech. Metal, element, compound, atom, molecule, cell, organ, population, community, elastic, force, and speed are concepts in this sense, but ideas such as "hydrocarbons burn," or "phenotype is determined by genotype," are more complex than concepts.

Research by Klausmeier and his associates (cf. Klausmeier, et al., 1974) and by Markle and Tiemann (1969) has provided useful insights into concept learning. After identifying the attributes that must be present in order for an entity to be a member of the concept class and identifying those attributes that vary across examples and non-examples, Markle recommends that the student be presented with examples which are carefully selected to show characteristics that may or may not be present in members of the concept class and show non-examples which are carefully selected to illustrate those characteristics that *must* be present in order for an entity to be a member of the class. This strategy has proven to be very effective in teaching concepts for which appropriate examples can be found.

Unfortunately, there are concepts in science which have no visable examples (atom, for instance) and there are concepts that have examples which do not reveal the defining characteristics (samples of elements and compounds, for example). We attempt to get around these problems by using physical models, illustrations, and analogies as "pseudoexamples" which clarify the concepts (Herron et al., 1977).

Perhaps the preceeding discussion of concept learning and the use of analogies seems strange in a section dealing with feedback. They certainly do not involve feedback in the conventional sense of providing knowledge of results. However, the research on feedback, concept learning, and the efficacy of analogies all emphasize the importance of providing the learner with information that he or she can process to make sense out of experience.

8. Things that make sense are remembered for a long time but nonsense is not. There can be little doubt that much that we call learning is nothing more than rote memorization of meaningless material that is repeated for an examination and quickly forgotten. There are several reasons for this. For one thing, we try to teach too much.

McKeachie (1978) describes (without citation) an argument between teaching fellows. The essence of the argument is whether students will retain more information about the nervous system if they are taught only those basic essentials that we want everybody to learn, or if they are presented much more detail than they are expected to retain. The argument was resolved by a study that showed that students who were taught only the essentials clearly did better on final exam questions over the nervous system. Research by Katz (1950) also supports the generalization that, after a point, adding information does little more than cause confusion and decrease what is actually learned.

Learning is far more effective when material is presented so that the *learner* can fit ideas into a meaningful context. (Remember that the teacher, who has superior knowledge of the subject, may see logical connections that are not at all clear to the beginner.) The teacher can often assist in this process of knowledge assimilation by calling attention to the relationships or by asking questions that prompt students to juxtapose and integrate ideas. Too often teachers see discussions that review and tie together ideas as detrimental to learning because they reduce the amount of material that can be covered. However, research suggests that, on the contrary, activities that assist students in placing information into some meaningful context lead to more learning and greater retention.

Practice enhances retention of information and the development of cognitive skills. However, the kind of practice influences effectiveness. A number of experiments have shown that practice in context (for example, practicing the use of metric units in the context of making measurements for other purposes), and practice with a variety of problems which help to develop principles rather than teach a pattern, is more important than repetition alone (cf. Wolfle, 1935).

Students who have been taught an algorithm often solve problems like those used in the teaching better than do students who are taught the principles behind the algorithm. However, when the problems are varied slightly from those used in instruction (as they invariably are in out-of-class applications), those students who understand the principles of solution do better (Mayer, 1974). This does not mean that it is inappropriate for students to learn algorithms for problems that are solved repeatedly. Students through the years have all learned algorithms for manipulating algebraic equations and probably used them before they understood the principles on which the algorithms were based. Through practice, they became very efficient at solving algebra problems. However, the algebra took on new meaning when they began to use it in science classes. Egan and Greeno (1973) suggest that a combination of algorithmic practice and meaningful practice is probably the best strategy.

Not only do we try to teach too much and teach it too superficially, we often put together closely related ideas in such a way that we invite confusion.

9. Two closely related ideas are easily confused when they are taught at the same time. However, when one is already well known, the other is quickly learned by contrasting the new with the old. There are several, similar card games called rummy. If one is known, another can be learned rather quickly by contrasting the new game with the one already known. However, if an individual does not know any of them, and attempts to learn two or three of the games simultaneously, there is an excellent chance that the person will confuse the games and make errors while playing one of them.

There are many ideas in science that are closely related, and these are often taught simultaneously. Examples would be molarity and molality or the three acid-base theories taught in most chemistry classes. Logically, they go together. However, it would appear that there is less chance of confusion if one of the related ideas is taught and practiced until it is clearly understood before another is introduced. When the related idea is introduced, it can be compared and contrasted to the familiar concept, with a focus on the similarities and differences to clarify both ideas. Note that this strategy is very similar to the strategy for teaching concepts that was described earlier. There, examples of a concept and examples of what it is not are contrasted so that the student understands those characteristics that must be present in order for something to be an example of the concept as well as those characteristics that may be present in both examples and non-examples.

Strategies of Teaching

It may seem surprising that nothing has been said about classroom organization or the way that information is presented, even though a great deal of research has been done in these areas. This is not an oversight. Generally, the research would suggest that most teaching strategies can be effective under given conditions. They can also be totally ineffective under other conditions. In other words:

10. The packaging of the product is far less important than the quality of what goes inside. Straight lecturing has been maligned for years, but observation of classrooms from junior high through college will show that the practice is far from dead. Most of the research indicates that information can be conveyed in writing more efficiently than through lecturing—provided the writing is read. Research which contrasts lecture with discussion suggests that lectures are generally more effective in conveying factual information, but discussions are more effective in accomplishing higher level cognitive objectives, such as integrating ideas or developing problem-solving skills. Since we are more interested when we are more involved, discussions generally lead to more favorable attitudes and higher motivation as well. The strategy that should be choosen will depend on what the teacher hopes to accomplish. (McKeachie, 1978, provides a good summary of this research.)

One of the controversies in science education during the past decade has been over the relative importance of expository and discovery learning. Weimer (1975) did critical analysis of studies that compare discovery oriented and expository instruction in the fields of mathematics, science, language, geography, and vocational education. The studies analyzed focused on retention and transfer. The author reported that no evidence of a single superior method of teaching was indicated. As mentioned above, this is generally the case.

Some hint of the conditions under which discovery learning may be better or worse than expository learning is found in a study by Danner (1974). In his analysis, he found that the expository method of instruction was more effective when a difficult lesson on pressure was being taught. Conversely, the discovery approach was more effective when an easier, pendulum lesson was taught. It seems reasonable to assume that expository presentations are better when the material to be taught is so difficult that students are unlikely to discover important relationships on their own, while discovery approaches are preferable when such relationships are more transparent. Because of greater student involvement, discovery strategies are generally more interesting.

What is said above assumes that the goal of instruction is for students to gain information or clarify ideas, using logical operations that are already familiar. If intellectual development is the goal, active mental involvement on the part of the student appears to be quite necessary, and that type of involvement is more likely to occur under instruction that is generally described as discovery learning. One type of discovery learning, the Karplus learning cycle, has been the basis for a program designed to enhance intellectual development (ADAPT, 1976), and similar kinds of activities are characteristic of several other programs (Arons, 1976; Lockhead, 1977).

Various kinds of self-paced and/or individualized instruction have found application in recent years. Some have been effective and others have not. The research on individualized instruction is closely related to research on mastery learning. The ideas frequently appear together.

Okey's (1974) study of mastery learning appears to be typical. Of five teachers in his study, one produced greater gains among students using a mastery learning strategy. In no case did students suffer from this approach, but it did not always seem to help. We may reasonably ask why.

The answer may lie in how students react to the increased responsibility that normally accompanies mastery or individualized strategies. Some students are confused and frustrated by freedom of choice and do not achieve very much as a result (Humphreys & Townsend, 1974). Furthermore, students may not be able to plan a sequence of instructional activities as well as the teacher (Gunter, 1974). In addition, less able students either cannot interpret the feedback that they receive or they lack motivation to do additional work even when feedback indicates that it is needed. In any event, we know that students at the bottom of an ISCS class are more willing to skip instructional activities than students at the top (McCurdy, 1975). Findings such as these and the well documented fact that students in an individualized program tend to procrastinate, suggest that we need to provide some safeguards if we expect students to achieve in individualized programs. Students are helped when the units of study are kept short, when feedback is frequent, and when progress is carefully monitored.

In a recent review of individualized programs, Kulik and Jaksa (1977) suggest that, of the various strategies for individualized instruction that have been used at the college level, PSI gets the highest marks. Although they acknowledge the reality of procrastination and other problems mentioned above, they believe that the preponderance of evidence suggests that achievement is considerably higher under the PSI format than other teaching formats. They attribute much of the success to the frequent feedback which characterizes this teaching strategy. Audio-tutorial instruction also shows increments in achievement but the advantage does not seem to be quite as large.

How important is the laboratory? This question has been investigated for years with no resolution. Again, the evidence suggests that the *way* the laboratory is used is more important than whether it is present or absent. As McKeachie (1978) remarks in his summary of research on laboratory teaching, "Whether the laboratory is superior to the lecture-demonstration in developing understanding and problem-solving skills probably depends upon the extent to which understanding of concepts and general problem-solving procedures are emphasized..." We all know that we have gone through laboratory exercises in a rote manner without having the slightest notion of what we did or why. We also know that we have gained real insight into complicated ideas by participating in laboratory activities. Certainly the observation of actual phenomena can help clarify ideas, but looking without actually seeing is of little value.

With the increasing popularity of Piaget's ideas among science educators, many people seem to have the mistaken notion that any kind of concrete experience will help students who operate at the concrete operational level. This is not so, as is illustrated by a study in mathematics education by Kulm (1977). It was hypothesized that concrete operational students who had math labs would achieve more than similar students in a lecture section. It was hypothesized that students operating at the formal operational level would not. The results indicated that just the opposite to this prediction was true. Analysis of the activities done in the laboratory strongly suggests that the logic needed to understand the laboratory activities was that of formal operations. If concrete experiences such as those encountered in the laboratory are to be beneficial, the logical operations needed to make sense out of those experiences must be the logic that is familiar to the students. In other words, concrete experience may be *necessary* for understanding some ideas, but it is certainly not *sufficient*.

Conclusion

Research never will provide all answers to all questions about teaching science. Conscientious teachers will always need to make judgments based on their own experience. They will need to keep their eyes open and their ears tuned for feedback that will indicate what is going wrong and how it can be made better. Still, it is not necessary to learn everything on one's own.

Research seldom tells us specifics about what to do on Monday morning in Science 101 but it certainly does lead to generalizations which the thoughtful practitioner can use as a guide. Some of those generalizations have been mentioned in this article and discussed in terms of supporting research. If the guidelines are used by the classroom teacher, we will have made *some* progress toward closing the gaps between research and practice.

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Forum

Christine I. Bennett

Richard L. Turner and William J. Gephart respond differently to the question "Is student learning failure due to teaching failure?" Readers are invited to react to either or both essays, or to contribute a different response to the question.

Is Student Learning Failure Due to Teaching Failure? Affirmative.

by Richard L. Turner

The question of whether failure in student learning results from failure in teaching is a treasure of ambiguity. It also presents one of the major issues in twentieth century liberal educational thought. Affirmation of it underlies the accountability movement, the social-educational legislation of "The Great Society," Public Law 94-142, the Education of All Children Act, and the hopes of all instructional developers. Contemplation of it drives teachers into neurosis and principals to jobs in the private sector. It is the fickle darling of education. What, though, are its ambiguities? How do they arise? In view of them is it sensible to affirm the question? These are the issues to be examined.

Four Dimensions of Abmiguity

The ambiguity of the question issues from its four identifiable dimensions. First, it has a logical dimension. To deal with this side of the question, one must ask, "If I agree to the proposition 'Student learning failure is due to teaching failure,' what other propositions have I, by implication, also agreed to?" Second, it has a value side. Along this dimension one must probe what the worth or value of teaching is if its value does not lie in student learning. Third, there is an emotional side to the question. The issue here is whether or not teachers could reasonably be expected to remain in an occupation in which each perceived or alleged student learning failure was blamed directly on them. The fourth dimension of the question is empirical. Along this dimension one must ask what portion of student learning is indeed attributable to teaching.

The Logical Arguments

Several years ago B. O. Smith (1961) introduced a set of arguments intended to cast doubt on Dewey's analogy: Selling is to buying as teaching is to learning. The analogy was intended to point out that teaching-learning is a reciprocal exchange, or transactional relationship. The analogy has an oblique implication, however. If buyers are not buying, sellers are not selling; hence, if students are not learning, teachers are not teaching. By subtle inference this analogy affirms that a failure in student learning makes the calibre of teaching, if not its very existence, extremely suspect.

Smith pointed out, however, that the analogy is by no means perfect since statements of the form "I taught X to A, but A did not learn it" are meaningful. Teaching can occur, according to this statement, quite independently of learning. Teaching is viewed as a set of actions that are intended to produce learning but do not always do so. It is like hunting. One can engage in the sport without bagging the quarry.

The difficulty with the argument that teaching is like a stalking sport is not that it is false, but that it does not implicitly recognize differences in success among stalkers. The question when one returns from a day in the field is not what he has been doing all day, i.e., hunting, but whether, to put it in bucolic terms, he "got anything." This question is obviously not about whether a recognizable form of activity occurred, but rather, having occured, was the activity of value or worth.

The question, Is student learning failure due to teaching failure? cannot in fact be resolved on logical grounds because the meaning of "teaching" does not strictly include the idea of learning, only "successful teaching" includes the latter idea. Based wholly on logical arguments, then, the affirmative position on the question is lost. Teaching does not by logical necessity eventuate in learning.

The Value Arguments

"Is student learning failure due to teaching failure?" is a value question. It cannot be answered by logical means until one decides how the value or worth of teaching is to be counted. As posed, the question under debate assumes its own value position. The true form of the question is, "Is the worth of teaching to be found in student learning?" If one answers this question in the negative, he must either take the position that it is impertinent and irrelevant, hence make a sophistic attack, or take the position that the true value of teaching lies elsewhere than in learning. It might, for example, lie in providing jobs for the otherwise unemployed or in keeping children off the streets.

Yet one can see that there is a broader ambiguity in the value dimension of the question posed. To say that the value of teaching lies in student learning implies that student learning is valued either as a good-in-itself or is a means to other goods, or perhaps a little of both. Social attributions of value to school learning quite obviously change. From a liberal or humanistic educational viewpoint, learning as the development of the potential of the individual is a good-in-itself. The enhanced development of self is the main purpose of living. From a conservative educational viewpoint, student learning is a means to other goods, especially economic goods.

These social values seem at first remote from the question, but further reflection reveals that teaching might be quite successful in the perspective of liberal values but a failure from the standpoint of conservative ones. Both sets of values affirm that the worth of teaching is intrinsically connected to student learning, hence affirm that student learning failure is due to teaching failure. Yet, the differences in the two value positions permit the proposition: My students learned extremely well, but I was a failure in teaching them. This proposition can be true if what was successfully taught to students was considered to be of no worth. The meaning of "teaching failure" is broader than the meaning of "student learning" since it includes the worth of the student learning in the eyes of the social group as well as consideration of whether or not learning actually occurred.

In sum, from a value viewpoint, one must affirm the proposition that student learning failure is due to teaching failure. The question of teaching failure can arise, however, either because students did not learn, hence the teaching was of no general worth, or because the students learned but they learned things to which no social value is attributed, hence the teaching was worthless and therefore a failure. Teachers do indeed have a difficult time winning the teaching game.

The Emotional Arguments

Along this dimension, the issue in the question posed is whether teachers could emotionally, or from a mental health viewpoint, withstand working in an environment in which they must accept blame for student failures in learning. One could affirm that student failure is attributable to teaching failure only to discover himself to be the cause of widespread emotional disturbance among teachers, leading ultimately to the general demise of the profession. Who would care to belong to a profession if a consequence of joining it were a nervous breakdown?

The basis of an emotional response to the notion that the failure of students to learn is attributable to one's failure as a teacher may be found in behavioral psychology. To sustain behavior over a period of time some form of reward for the behavior must occur. Moreover, the reward must be greater than the personal cost of obtaining it. In teaching, one of the main rewards is observing students as they develop knowledge of a subject, skills and personal social-emotional growth, as a consequence of one's teaching efforts. Yet, as Smith pointed out, teaching does not always result in learning. Indeed, in some classrooms with some students, a very great amount of teaching effort results in very little noticeable student progress. The level of reinforcement for the teacher is quite small. The number of frustrations is quite large. The personal cost for making the effort to teach is not offset by the amount of reward received.

A common response of teachers who are frustrated by in adequate student learning is to observe that the students one must teach are in fact not very teachable. Student learning failure, they maintain, is not attributable to teaching failure, but rather to the characteristics of the students themselves—their intractability, their stupidity, their inadequate preparation to undertake the level of education at which someone has, for unexplainable reasons, placed them.

If one believes that student learning failure is attributable to teaching failure, the common response of teachers as outlined above may be seen as a psychological rationalization, as a defense against failure, a way to decrease the personal impact of great effort for little reward. From the viewpoint of the writer, it is a critical rationalization for teachers—one that permits them to continue in the field rather than withdraw from it, that permits them to retain reasonable emotional stability under unfavorable emotional conditions.

The problem is, however, that both American education and American society hold a very strong affirmative value position on the question, "Is student failure due to teaching failure?" Indeed, the strength of this position appears to have increased markedly in the past 10 years. It has lead both to the accountability movement and to the competency-based test movement. The difficulties with these movements from the viewpoint of the teacher is that they simultaneously make it difficult to rationalize failure and at the same time intrude specific values into the classroom.

The accountability movement has as its basis the proposition, "The worth of teaching is to be judged by student learning," while the competency-based movement specifies *which* student learnings (the "basic skills") are to be valued. Thus, teaching which does not emphasize basic skills outcomes is of less worth, or is worthless, compared to instruction that does emphasize them. The teacher is clearly trapped. Rationalization of failure is not permissable. Moreover, failure of a teacher to achieve selected learning outcomes, whether or not they represent the teacher's goals for instruction, means public exposure for failure. The results seem predictable—withdrawal from teaching when this move is economically possible, increased conflict, and rising tension accompanied by increasing emotional problems and physical symptoms attributable to emotional stress. One may indeed affirm that student learning failure is attributable to teaching failure, but from an emotional viewpoint it seems quite unwise to do so.

The Empirical Arguments

Empirically, speaking, a very large percent of student learning cannot be directly attributed to variability among teachers—to being taught by a less proficient rather than a more proficient teacher. About 60 to 65% of student learning can be attributed to factors other than teaching and about 10 to 15% to the individual teacher, with the remaining percent being unaccounted for. Therefore, although one can attribute student learning failure to teaching failure, one cannot attribute much of the failure to any one teacher. Nonetheless, the effects of poor teaching are cumulative over time. Consistent exposure to poor teachers for the six years of elementary school creates a growing deficit in student learning. A child may recover from one poor teacher, but will have difficulty recovering from bad schooling. Empirically, it seems more accurate to say that the failure of students to develop to their full potential is traceable to the cumulative impact of poor teaching, hence bad schooling, than it does to say or to imply that some sort of one-to-one correspondence exists between learning failure and teaching failure.

The fact is that when teaching is done in a group setting, some children learn quite well while others do not. It is extremely likely that all children in a classroom will in a given year learn something. Indeed they will learn quite a bit. Empirically, "student learning failure" is a statistical entity. It has meaning only by reference to some specified performance identified as important by some person or group or by reference to the performance of some comparison group. Thus "student learning failure" is always relative. So is teaching failure. Very few teachers "fail" in any direct, observable sense; rather, they fail by comparison to other teachers or to alternative technologies. The empirical arguments bearing on the question, Is student learning failure due to teaching failure? do not yield very clear results for individual cases. One cannot infer from statistical results that a particular failure in learning is due to a particular failure in teaching. One cannot affirm the original question in this way.

Yet, the empirical arguments are very powerful from a policy or general social viewpoint. Some teachers are much better than others. The effective behaviors of the the better teachers can be identified, as the Medley report (1977) demonstrates. Students systematically exposed to better teachers will over a period of time be considerably advantaged compared to those who are not. It follows that a systematic effort to improve teaching by both better selection methods and by better training will have long-term social benefits in advances in student learning. From a policy viewpoint, the question must be affirmed.

Conclusion

The idea that student learning failure is attributable to teaching failure is a very important, but also very ambiguous one in American education. Its ambiguities permit many different kinds of arguments to be mounted for and against it. Some of these arguments are better than others. The argument that learning failure is somehow logically connected to teaching failure is unsound. On the other hand, the argument that teaching *ought* to result in learning is a good argument since it reveals that the worth or value of teaching lies in student learning. Teaching which does not result in learning fails to yield value or worth. To be valued, teaching must eventuate in learning. If the idea that student learning failure is due to teaching failure is pressed to the point that teachers are held personally responsible for student failure, unfavorable consequences may be predicted to follow. Teachers cannot emotionally withstand being held accountable for learning failures over which they may have little control. Therefore, if the idea is either taken personally by teachers or used personally against them, the idea should be disaffirmed. It does not follow, however, that the idea should be generally disaffirmed. As an analysis of the empirical arguments reveal, evidence for both learning failure and teaching failure is comparative and group- or population-related, hence statistical. Affirmation of the idea from a policy viewpoint is in turn important since it places social emphasis on improving teaching as a means of achieving the social benefits that follow from increased student learning. In the long term, the concept that student learning failure, and student learning success, are attributable to teaching must be affirmed. To advocate otherwise is to affirm that teaching is, after all, of very little consequence.

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Is Learning the Principal Criterion for Evaluating Teaching?

by William J. Gephart

The accountability movement, competency based education, minimum competence testing, and educational malpractice suits seem predicated on the assumption that learning will occur *if* good teaching exists. That assumption does not hold. Teaching and learning are separate processes—sometimes linked together and sometimes occurring individually. Thus, to demand success in one of them as a criterion for the other is to over simplify their nature individually and collectively.

I would be willing to guarantee that I could teach a specific child anything. I would make that absolute guarantee if I were given the same level of control over the learning environment. And, I would make that commitment with little or no concern about failure. If B. F. Skinner can teach a pigeon to count, I ought to be able to teach a child anything. A child has much more intellect than a pigeon and if a pigeon, with its limited reasoning power, can be taught to count I ought to have no trouble teaching a child.

But, Skinner had absolute control over the life of his learner. It was possible in the "teaching" to use instructional techniques such as electric shock and starvation. So, if I am to make an absolute guarantee about the results of my teaching with a child, I must also demand absolute freedom in the selection and use of instructional methods and techniques. Physical punishment and starvation are harsh ways to promote learning, ways most educators find abhorant. But, they have been used in the past and continue to be used today. Starvation (probably less offensively called denial of food) is a technique used effectively with the approval of parents in the education of autistic children. Physical punishment is also used with parental permission in some schools to direct the learner's expenditure of energy in the direction of the desired achievements. In most educational settings parents and the school community will not sanction the use of electric shock and starvation. (Thank goodness; I, for one, would not want to use them.)

If constraints are placed on the instructional procedures at my disposal, I must in return demand that comparable limits be placed on the guarantee I am asked to make. A negotiation has to take place. If the community wants me to guarantee certain results, then I will have to do A, B, C, D. . . . If the community will not permit me to use technique A or will not provide the money needed to do technique B, then I will have to reduce my guarantee. Rather than a guarantee that my students will learn topic X, I will guarantee that as a teacher I will do certain things in my *attempt* to help my students learn.

When this negotiation is completed the participating parties involved have delineated the tasks to be performed by the teacher and the ends, the goals, to be accomplished by the learner. In so doing they have outlined a teaching process which, if carried out as delineated, must be considered as a performance of acceptable quality. If we agree that as a teacher I am to do a specific set of activities constrained in particular ways *and I do them,* there are no solid grounds for disparaging my teaching regardless of whether the students master or do not master the material.

An example may help make the point. In driver education one might have the development of respect for and obedience to speed limits as an objective. If that task has to be done in a setting where the vast majority of drivers violate speed laws with impunity and laugh at them, the teacher should not be judged on whether his/her students violate or obey speed laws. Rather, that teacher ought to be judged on the basis of the instructional procedures followed.

One of the factors that affects the ability to guarantee the results of most instruction is the fact that the student controls the energy required to learn a specific item. The teacher does not. If it requires X units of mental energy to memorize the Periodic Table, the student determines whether or not he or she will expend that energy! The teacher can manipulate the environment in some ways to try to effect the energy expenditure. But, the teacher does not expend the learning energy. The student does. So, the bottom line is what the learner does. If, as teachers we are given so much control that our manipulations will coerce the necessary learning energy expenditure, we can guarantee learning and accept responsibility for its accomplishment.

To say that teaching failed if a student did not learn is a statement that must be qualified. Good teaching can occur without learning. A teacher who uses all the techniques appropriate for the accomplishment of a praticular educational goal must be accepted as a good teacher. That person cannot be held totally accountable as long as the learner is free to decide whether or not to expend the energy to learn. To do otherwise would be analogous to holding the physician responsible if his patient dies. The physician is responsible for carrying out accepted medical practices.

The points made above should not be interpreted as an argument that evaluating the quality of teaching should focus only on teaching process variables. That interpretation cannot be made until the purpose of the evaluation is made specific. The evaluation of teaching can serve several purposes: (a) self-improvement of instructional skills, (b) administrative structuring of the strongest possible program, and (c) establishing accountability. Sometimes we evaluate my teaching to give *me* information *I* can use in decisions *I* made about changing my instructional procedures and techniques. That is purpose number one. Purpose two is being served if we evaluate my teaching to give *administrators* or *supervisors* information *they* can use in decisions on how *they* are going to use me (assignment, pay, retention, etc.). The third purpose is served when my teaching is evaluated along with others to determine how well the program objectives are being achieved.

To serve the first evaluative purpose I need both process and product information. I need to know what my students accomplished *and* how I carried out the instructional procedures and techniques I used. If I do not get information on my students' ability to do work of the sort we have worked on, I cannot decide whether changes are needed or not. If I do not get information on the techniques and procedures I used, I cannot be confident about what instructional changes I need to make.

The second evaluative purpose requires information on outcomes—what educational goals are and are not being accomplished—and information about the instructional skills of the individual staff members. Without both process and product information, decisions about releasing an individual staff member, or about which teachers should be assigned to which instructional tasks, are subjectively based. In too many cases the person whose teaching skills are almost non-existent is not released because solid evidence is not available. And, some administrators determine instructional assignments by asking the individuals what teaching assignments they would prefer.

Evaluative purpose three focuses primarily on two questions: What were the goals we asked our schools to accomplish? and, What were the results of their effort? The comparison of the answers to those two questions gives the school's policy makers information useful in deciding the focal points for further improvement efforts. This is a policy question. It is not automatically focused on an individual teacher.

Teachers, administrators, and educational policy makers need to recognize three things. First, different levels of decision making about the quality of teaching call for different kinds of data. As a result, the evaluation procedures differ for each of these evaluative purposes. Second, when an evaluation focuses on an individual teacher's work, student achievement is not the ultimate criterion. A negotiation of outcomes and procedures to be used must be used. Third, evaluation of teaching performance is threat inducing. The readers of this article have been judging its value from the time they started reading. Some will have judged it of little value and will have stopped reading it long before reaching this point. Others will have judged it useful and will still be reading. Still others will have deferred judgment to some later point. The possibility of large proportions reaching the first of these conclusions is threatening to the author. The fear of being judged inadequate is always present when an evaluation is undertaken.

The threat of being evaluated must be attended to in the design of an evaluation. Failure to do so can markedly affect the quality of the data. To gather accurate data on the way a person teaches requires a great deal of cooperation by that person. If the person feels much threat in being evaluated, he or she will be very cautious about the degree to which they will display perceived weaknesses. If the evaluation is done in a way that suggests that information can or will be used punitively, the person being evaluated will be very careful about his or her participation.

Summary

Learning is something done by the expenditure of energy of a person. Teaching is something done to try to influence the expenditure of energy in directions or in ways that given material will be learned. There are many techniques a teacher can use for directing a student's expenditure of energy. *But,* the student expends the learning energy, not the teacher. Further, the student, not the teacher, decides on how much energy to expend. For the teacher to guarantee that the students will expend energy in specified ways, the teacher may have to use techniques that are outside generally accepted practice, techniques that society usually bans from the educator's repertoire. In recognition of these circumstances a negotiation needs to take place that results in specification of what constraints are being placed on instructional technique and the extent to which the teacher can be held accountable for failure of a given student to learn.

This is not an argument against the use of student achievement in evaluation of teaching. Rather, it is a plea for clarifying the context in which teaching is conducted so that a more adequate evaluation can be carried out.

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Legislation

David H. Florio

Education's Big Four in the 95th

Bleary eyed after a marathon 34-hour final session, members adjourned the 95th Congress. Among the flood of legislative actions in the final days, four major education issues were decided. These actions, marking the 95th as a major education Congress, were (a) approval of the Education Amendments of 1978, (b) passage of the second consecutive large increase in appropriations for the Education Division of HEW, (c) support for middle-income student assistance and the rejection of tuition tax credits, and (d) killing legislation to establish a cabinet level Department of Education.

The centerpiece of the 95th's education achievements is the omnibus Education Amendments of 1978 (Public Law 95-561), which extends the authority for the Elementary and Secondary Education Act (ESEA), adult education, impact aid, bilingual education, Indian education, emergency school (desegregation) aid, and a variety of other special and general education provisions through Fiscal Year 1983. Another major accomplishment was the approval of an additional two billion dollars within a twelve-billion-dollar appropriation for HEW's Education Division. Among the most controversial Congressional actions was the rejection of tuition tax credits for elementary, secondary, and higher education. The approval of the middle-income-focused College Opportunity Act was a major victory for the Carter Administration and the coalition of education groups opposing the tax credits. A reversal of these decisions would have either forced a Presidential veto or caused a major shift in the type of federal aid to education.

The loser of the group was the President's proposal to establish a Department of Education. The Department of Education Organization Act, approved by the Senate, was withdrawn from final House action when a handful of opponents threatened to use delaying amendments and procedural rules (the House's functional equivalent of the "filibuster"). Vice President Walter Mondale and several Senate leaders have promised to introduce similar legislation in the 96th Congress which convenes in January.

The emphasis on education in 1978 has helped to establish President Carter as a pro-education President and has marked the 95th Congress as education's significant supporter in a dozen years. Yet, there is no major overt rationale for this to be education's year. President Carter rarely mentions education in his public utterances. Education is not among the three Big Es on the domestic scene: Energy, Employment, and Economy (including taxes and inflation). Education committee assignments are not popular among members of Congress. Perhaps most significant and incongruous, all of these education related actions were taken by Congress three weeks before an election in which fiscal conservatism and tax cutting were the major themes.

These legislative actions strongly reaffirm the federal role in education and place substantial funding behind the authorized programs. Behind what appears to be a fairly gutsy set of moves by the Congress and Administration, is a complex of circumstances, principles, interests, and pieces of information. In the following sections, this report will highlight some of those forces behind the education actions of the 95th Congress and Carter Administration.

The Education Amendments of 1978

With the exception of the tax credit issue, one could safely say that most of the members of the 95th Congress had little intimate knowledge of the complex issues dealt with in authorizing and funding the programs in the Education Division of HEW. The massive 1978 amendments, with significant changes in implementation, administration, and intergovernmental concerns, did little to alter the type of federal aid to education. That aid, being a set of categorical programs, concentrated on those publics most in need and for those areas of national interest perceived as neglected by the education establishment.

For the 1978 Amendments, momentum and establishment were the prime movers. Over the past dozen years, federal support for education has become well established. Aid to education is also now large enough to be considered federal "pork" among states and Congressional districts. Although authorities for education have always had time limits, momentum for reauthorization is powerful. Major cycles of education legislation—e.g., elementary/secondary, higher/ postsecondary, handicapped/vocational—are now set in motion. An attempt to eliminate, significantly alter, or reduce federal aid and programmatic support in one of these arenas is extremely difficult. Like a giant amoeba, these omnibus pieces of legislation can swallow-up any small scale reform effort.

The establishment and momentum of federal aid to education has changed many assumptions and questions that come into play during policy deliberations. Issues center on formula, administrative, implementation, and intergovernmental concerns. Legislative improvement rather than fundamental change or attack dominate legislative debates. Although there were several substantial efforts to change ESEA (e.g., proposals to move from categorical to general types of aid or to broaden the target of compensatory aid to include all children with educational problems), most of these were turned back in 1978.

The momentum and establishment also changed the way in which negative publicity is handled. Although education could not compete with some of the most powerful domestic issues for national publicity, it did receive its share. Test-score decline, financial crises, school violence, teacher strikes, and the post-Proposition 13 blues seemed to capture some media attention. Instead of forcing a major attack on federal programs that did not anticipate or solve such problems, these forms of negative publicity often served to strengthen the federal role in education. First, crisis is a powerful policy motive in this country. Second, the strength of well-established expectations for federal aid to state and local governments seems to preclude massive reductions. Third, shifts in elementary and secondary education policy are seen in tone and theme rather than type. PL 95-561, for example, places its emphasis on "improvement, quality, and the basic skills." This is a shift from previous stress on innovation and change.

Momentum and establishment may be necessary, but they are hardly sufficient explanations for the complete redrafting of federal elementary and secondary education authorities. While service on education committees may not be popular, federal aid to education is. While interest in myriad issues in omnibus education legislation is limited to a handful of members, the Congressional staff has grown in its knowledge and sophistication of educational issues. Intimate knowledge in any legislative area is limited among members of Congress; however, there are plenty of education interest groups that are willing and able to provide advice and information.

The growth in the size and sophistication of education staff on Capitol Hill has been more than matched by the growth of education interest groups. The decline in the seniority system and the power of party and committee leaders in Congress has been accompanied by the increased influence of interest groups. This is just as true for education as for other policy areas. State and local education agencies and nearly every type of education (supported with federal funds) seem to have a Washington based association or representative. These groups have, or are quickly learning, the essential political skills of moblizing grass roots support and building coalitions. The political world, once viewed as tainted by many educators, is now a prime concern for teachers, administrators, parents, and others with special areas of interest. The poor tourist wishing to see a Congressional hearing, mark-up session[1], or House/Senate conference[2] must fight for standing room.

Another significant reason for the detailed consideration of this massive legislation, is the number of interested and knowledgeable staff in the Administration.

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[1] Mark-up sessions are Congressional committee and subcommittee sessions designed to prepare bills for the next step in the legislative process. A bill, introduced by a member, is literally "marked up" with amendments changing or adding to the original draft.

[2] Conference committees are meetings of representatives of the House and Senate authorizing, or appropriations committees responsible for, the legislation in question. The purpose of such sessions is for conferees (called "managers") to compromise on the differences in legislation passed by both houses of Congress. The form of legislation is called a conference report which cannot be amended. The respective bodies agree to the report or refer it back to the conference. A great deal of policy is decided by the managers and staff.

Administration personnel from the policy and legislative staff of the White House, Office of Management and Budget and HEW were involved in the consideration of PL 95-561. Representatives of HEW's Assistant Secretary for Education (ASE), Office of Education (OE), National Institute of Education (NIE), Assistant Secretary for Planning and Evaluation, and General Council were all seen on Capitol Hill. Their interest is not only in the general program authorities but also in the management and administrative fine tuning of education legislation.

Unlike the Nixon and Ford Administrations which pushed for changes from categorical to more general types of aid, e.g., education revenue sharing and block grants, this Administration has chosen "access and quality" as its overt theme and "improvement in management" as motivation for specific changes. For example, the legislation includes a separate section designed to reduce paperwork burdens on education agencies and institutions receiving federal aid to education. Annual applications and evaluations for major service programs have been reduced to one every three years. Although the categories are retained and several new ones added, there is more emphasis on local flexibility in planning and developing program improvement strategies.

Another motivating force in the reaffirmation of the federal aid to education is the role of research and policy assessment. The Title I, aid to schools with low-income students, study conducted by NIE and the data on minority student achievement provided by the National Assessment of Educational Progress (NAEP) indicate that compensatory education is having a positive effect on its target population. Although such data did not demonstrate that ESEA has solved the Nation's education problems for students from low-income families, it did blunt many claims that the "Great Society" programs have failed. Title I was essentially reauthorized with an additional program for districts with high concentrations of low-income students.

Many of the changes in Title I were designed to strengthen the administrative and evaluation provisions. A number of these administrative changes were inspired by an emphasis on the primacy of state and local education delivery roles. The federal, state, and local governments' emphasis on improved intergovernmental relations, coupled with the Congress and civil rights groups' efforts to stave off changes in the concentration on low-income children, resulted in the retention of categorical aid for children from low-income families.

Improvement, basic skills, proficiency standards, and quality were also significant themes in PL 95-561. The "back to basics" movement is woven into many of the Act's 15 titles. A new Title II, "Basic Skills Improvement," expands the Right to Read program to include support for improvement in the basic skills of "reading, math, oral and written communication." The old Title IV, which included support for innovation, has been changed to "Educational Improvement, Resources and Support." The improvement section emphasizes local school site improvement and is, in large measure, based on organizational change research over the past two decades. Title V continues support for improved program administration in state agencies and autorhizes a national council on education quality. Support to state and local education agencies establishing proficiency standards (with emphasis on reading, writing, and math) is authorized in a separate section. Care is taken, however, to preclude the federal government from establishing or requiring a national test.

The Act continues a pattern of support for demonstrations and/or service programs which the Congress determines to be of national need. The major categories include reauthorization for bilingual, adult, and Indian education and Emergency School Aid Act programs to assist desegregating school districts. Administration efforts to consolidate special education projects and smaller categorical programs met with minimal success. Although the Congress did provide the Commissioner with some discretionary authority and funds for dissemination, the list of special projects grew to 11 and several of the existing special categorical programs were given new titles or sections. Special Projects (Title III) includes metric education, arts in education, a new preschool partnership program (designed to help school districts' work with Head Start projects), consumer education, youth employment (working with career education and Department of Labor programs for Youth Employment and Training), law-related education, environmental education, health education, correction education, dissemination of information, biomedical sciences (designed to encourage and assist minorities who wish to enter such fields), and population education. Former special projects or small categorical programs given separate authorities include community schools, gifted and talented, women's educational equity, and ethnic heritage programs. Additional categoricals include a "safe schools" program to help reduce violence and vandalism, Indochinese refugee children aid, support for the International Year of the Child, a National Academy of Peace and Conflict Resolution, and aid to states to equalize school finance. Several authorities for guidance, counseling, testing, Defense Department Overseas Schools, and library and instructional materials resources are also continued.

These laundry lists of special categorical aid provisions indicate no diminution of federal concerns for special interests or national needs. Some of these provisions—such as desegregation aid, bilingual, adult, Indian, dissemination, women's equity, and gifted and talented programs—enjoy broad recognition as national needs. Several, however, are the concerns of a small group of members or an individual interest group. The advantage for these programs is the nature of omnibus legislation. It would be very difficult to capture the attention of an education committee to deal in isolation with such things as "population education" or "law-related education"; however, in the press to deal with a massive number of issues these programs are included. In short, if no one objects, the program has a good chance of being part of a log rolling effort, i.e., "If I approve your special interest, will you approve mine."

No report on the Amendments would be complete without notice of the only general aid piece of pork in the bunch—aid to federally impacted school districts (Impact Aid). What started in the early 1950's as support for school districts with large numbers of children from domestic military bases, has now grown to a form of general aid (no strings attached) support for school districts with children from families that live or work on federal property. Every Administration since Impact Aid's inception has attempted to curtail or radically reduce the program; however, it reaches nearly every Congressional district and all of the states. Surprisingly, some of the Carter Administration's Impact Aid reforms were approved.

Finally, the usefulness of the NIE Title I study provided an incentive for Congress to authorize a number of special studies and research programs in PL 95-561. The role of policy analysis, research and evaluation is growing with the massive burden placed on the education related committees of the House and Senate. More than 25 titles and sections of the 1978 Amendments directly affect research and related inquiry. The National Institute of Education, alone, was given more than 10 new research or special study assignments. In addition to the studies assigned as part of program authorities, PL 95-561 amended the General Education Provisions Act (GEPA) in a variety of ways affecting educational inquiry. A major study of all federal education program evaluations, exceptions from some paperwork control provisions for research studies, requirements for faster responses to Congressional requests for reports and data, and several other provisions were included in the GEPA changes. In short, Congress has not only recognized its need for better data and research-based knowledge, it is taking measures to specify where studies are to be conducted and, in some cases, such as the school finance study, is actually specifying the expected informational outcomes of such inquiry. In summary, PL 95-561 represents a massive amount of work. The forces behind this effort are complex, interactive, and, in many ways, subtle. Momentum, establishment, political pork, and a new Administration wishing to make its education mark are necessary but insufficient explanations for this Act. Decline in party discipline, increases in individual initiative, a larger and better informed Congressional staff, increased numbers and kinds of special interest groups, increased political sophistication among members of the education establishment, increased attention (due in part to increased lobbying) to state and local government concerns, and a rising attention to the results produced by educational inquiry are included in the mix of motives.

The old simplistic adage that, in matters legislative, the "President proposes and the Congress disposes," is hardly adequate. The Congress, with its own budget process, has greatly increased its independence from the executive branch. This move, greatly stimulated in the years of adversity during the Republican Administrations, has not been abated with the Carter Administration. Policy is made in the "iron triangle" of legislative politics, i.e., the Administration, the Congress, and the interest groups (none of which is a monolith). Initiatives may spring from any member of a committee or subcommittee and few members feel that they must clear their proposals with party or committee leaders. Good ideas still have a potential for being included in legislation; however, ideas (good, bad, or neutral) must run the gamut of the political process. The effort takes persistent vigilance, information, persuasion, determination, and a healthy dose of good fortune. The best of policy initiatives must have an informed advocate on the Hill who will be present and attentive when the issue is considered among the multitude.

Education Appropriations for FY79

If a budget is a signal of a political philosophy, the actual appropriation is the authority to implement it. FY78 was a good year for education funding and FY79 promises to be even better. Eight years of a Democratic Congress and Republican Administrations saw open hostility, including several over-ridden vetoes, between the legislative and executive branch actions on education spending. In the Carter Administration, the executive/legislative relationship and the outcome for education appropriations has changed substantially. There has been a 39% increase in education appropriations in the past two years (from $8.8 billion in FY77 to $12.2 billion in FY79). There is also a prospect for a supplemental appropriation for FY79 since several newly authorized programs were not passed in time for consideration by the 95th Congress, e.g., additional funding for the middle-income student assistance. Accounting for inflation, these increases provide real and substantial growth in federal education spending.

The President's FY79 budget request for the Education Division was nearly 20% greater than FY78. Congress' appropriation is 17% over the FY78 mark (with a likelihood that a supplemental consideration will increase the amount even further). These actions reduced fears that President Carter would attempt to buy off the education community with his Department of Education proposal. In fact, the President has used his budget requests as evidence of his commitment to education and the need for a separate department to manage the growing enterprise.

In addition to what is a real commitment to education funding, several accompanying forces have helped bring about these strong increases for education. HEW Secretary Joseph Califano, having neglected education in his first year, turned his attention and energy in 1978 toward education legislation. His direct appeal for increased education spending overcame several reductions proposed by the Office of Management and Budget. His interest is generated from at least two sources. First, Secretary Califano's professional history took him to the White House during the 1960's when many of the Great Society programs were created. Second, at the time of internal executive branch considerations for the FY79 budget, President Carter had not yet decided on his Department of Education initiative. There is no question that the Secretary wanted to keep the E in HEW. By focusing his attention on education, he hoped to demonstrate that education was not buried in his massive agency.

Another major force behind this year's budget request was the President's effort to provide a viable alternative to tuition tax credits. The President proposed an increase of $1.2 billion in post-secondary student assistance. Although only half of this was approved by the Congress, additional increases may be appropriated in supplemental considerations.

1978 was also an election year. Against a background of tax cutting and elimination of waste in government spending, there is still strong support for federal aid to education. In fact, most polls indicate that voters believe that tax-cutting revenue loses could be taken from waste and abuse and that important services should be unharmed. In addition to general voter opinion, there is a growing political awareness among education interest groups at the grass roots level of politics. Teacher unions have not only become major contributors to political campaigns, their members are also volunteering in campaigns. The growing recognition that education is a public interest and, by definition, part of the political process, is extended to a wide array of interest groups. Such groups know the difference between authorizations and appropriations, and their Washington representatives keep close watch on both sets of committees.

Finally, no discussion of education appropriations would be adequate without a peek at the new 96th Congress. Education interest groups may be very pleased with the budget requests and appropriations over the past two years; however, Washington is a town in which "long range" tends to be generally viewed in terms of months or, on economic matters, weeks. With the exception of the military and research and development, President Carter, who has been talking in terms of a "growth pause" in his FY80 budget, is now talking of no real increases and a freeze on federal hiring. Unlike the Nixon and Ford years, the 96th Congress is unlikely to be as antagonistic toward limits on federal domestic spending. As already noted, the 1978 election was dominated by tax-cutting and anti-government rhetoric. Many of the new Congressional faces, and there will be a large number of them, and several of those returning have run on these fiscally conservative themes. It is unlikely that we will see the recent level of growth in education spending continued over the next two years.

Student Aid and Tuition Tax Credits

The debate over tuition tax credits, primarily for middle-income families, grew more heated in 1978 with the proposal to include elementary and secondary education in the package. Under threat of a Presidential veto and with the availability of the Administration sponsored middle-income student assistance bill, Congress defeated the tax credits for elementary, secondary, and post-secondary education. The approval of the College Opportunity Act was a major victory for the Administration, the coalition of education groups opposed to tax credits, and for the education related committees of the House and Senate (Education and Labor and Human Resources, respectively).

Approval of tax credits for elementary and secondary education would not only drastically change the nature of federal aid to education, it would have also changed the Congressional actors responsible for such aid. Tax credit legislation is a product of the House Ways and Means Committee and the Senate Finance Committee. Congressional Committees jealously guard their turf. The tax credit proposal, viewed by many as the seed for a back-door education voucher scheme, presented a clear threat to the education authorizing committees. Tax breaks provide limited political payoff beyond their initial approval. They are uncontrollable expenses and, as such, remove authority for their control from authorizing committees responsible for certain domestic policy areas.

These issues also produced a major demonstration of coalition strength among the special interest groups. Hundreds of coalitions are formed and reformed in the process of legislative action; however, a major threat to a basic form of domestic spending can give rise to large and powerful coalitions. The "Coalition to Save Public Education" attracted teacher unions, school boards, parents, higher education groups, and a variety of civil rights and labor groups. Not since the early days of ESEA had such diverse interest groups come strongly together around an education issue.

Leaving aside constitutional, church/state questions, and charges leveled on both sides (e.g., opponents charging that tax credits would lead to further segregation and reduced support for those most in need, and proponents charging that the opposition was anti-Catholic and anti-ethnic), the tuition tax credit debate was a fundamental discussion of federal education policy. Should the decision have gone the other way (including Presidential approval), federal education support would have begun to change its essential character. Not only would there be a shift from categorical to general aid, but there would also be a shift to an uncontrollable entitlement program.

Legislation to Establish a Department of Education

As noted at the outset, the Department of Education Organization Act was withdrawn from final action in the House. Although there have been signals from the Administration and the Congress that the proposal will be renewed next year, the mood of the new Congress and the energy needed to mobilize support for such enabling legislation is not yet apparent.

The defeat of the proposal signals a number of other types of changes in the Congressional arena. The filibuster considered the domain of the Senate, now has its functional equivalent in the House. The House limits general debate on all legislation; however, current rules permit unlimited amendments to most legislation. This amendment/procedural obstructionism threatened by a handful of opponents is what killed the Department of Education legislation. Needing to decide on a mass of legislation in the final days of the 95th Congress, the leadership was unwilling to live with the delays. The Administration claimed to have the needed support, if the measure was allowed to come to a vote.

The House and Senate forms of the bill, as approved by the full Senate and the House Government Operations Committee, were substantially reduced versions of the Administration's proposal. The original proposal included the Education Division of HEW, science education programs of the National Science Foundation, Head Start programs, child nutrition programs from the Department of Agriculture, Defense Department dependent schools, Bureau of Indian Affairs schools, and several smaller entities. Child nutrition, BIA schools, and Head Start were all cut from both bills. The House version also eliminated NSF programs and several minor provisions. Both House and Senate Committees (Government Operations and Governmental Affairs) added the Vocational Rehabilitation Services Administration from HEW and greatly strengthened the provisions for the Office of Civil Rights in the proposed department. Veterans' education and Labor Department Employment and Training programs were not even considered.

Once again, interesting coalitions of proponents and opponents were formed. The support for a Department of Education among education groups has been described as being "a mile wide and an inch deep." The National Education Association is the most obvious proponent of an education department. Clustered around the NEA, are a number of smaller groups who have taken stands in support of the department. The major opponent is the American Federation of Teachers which has been joined by an interesting coalition of civil rights and conservative opponents. Civil rights groups fear dominance by the larger teacher union and a break up of the labor/civil rights coalition which supports federal aid to education targeted on poor and minority students. The AFT stronghold is in the cities where high concentrations of such children live. The NEA, a long-time advocate of one-third federal funding for public education, believes that a separate department will increase the prestige, improve the bargaining position inside the Administration, and result in increased federal funding for education. Conservative groups fear that a separate department will increase federal dominance over state and local education and that the department will be captured by the teacher unions.

Missing in much of the debate and deliberation over the Department of Education proposal were the higher education groups. With the exception of the community and junior colleges, higher education took a back seat. The American Council on Education having sponsored a major study which called for the creation of the department, decided to refrain from active participation. Their concern seems to be that higher education will be dwarfed by the larger and better organized elementary and secondary education community, particularly the teacher unions. As the scope of legislation narrowed, their concerns were increased. Future action on this issue and the formation of coalitions on both sides of the issue will bear careful scrutiny.

Conclusion

This discussion of the four major education issues in the 95th Congress has provided the opportunity to analyze the complex forces involved in the determination of federal education policy. In many respects, these forces are representative of shifts in the broader arena of legislative politics. For example, the rising independence of the Congress, the growth and sophistication of Congressional staff, the decline in party and committee chair dominance, and the balance of power between executive and legislative branches all have powerful impact on the politics of education. Along with these shifts in Congressional action is the growing influence of special interest groups. For education, the number and type of such groups has grown dramatically. Recognizing that relationships with federal agencies are no longer, if ever, adequate, these groups have concentrated much of their attention on Capitol Hill.

The nature of federal support for education has given rise to increased attention to intergovernmental relations. Growing numbers of representatives from state and local government employees are seen and heard in the nation's capital. Federal aid to education has not only grown in size, but also in its complexity and burden. Regulations, evaluation requirements, and enforcement procedures have grown dramatically. These actions have given rise to the increased salience of the federated nature of educational governance.

Finally, coalitions are critical factors in developing or preventing federal education policy initiatives. These coalitions, temporal in nature, include interest groups, members and staff in the Congress, bureaucrats and leaders in the executive branch. The education community, long criticized for its fragmentation, is rapidly learning the nature of political bargaining and its concurrent necessity for building alliances.

As the 96th Congress convenes, these forces and shifts in policy formation will take new shapes. The Congress will be reauthorizing the Higher Education Act, the National Institute of Education, and other related programs. The Department of Education legislation will once again serve to complicate and capture the attention of the iron triangle. Tuition tax credits may surface again and the forces of the economy and the drive to reduce inflation also will come into play. In the meantime, interest groups and congressional committees will be overseeing the executive branch implementation of those programs authorized by the 95th Congress. As these events and tasks become more and more complex, the power of knowledge and information will increase. The ability to deliver needed and useful information in concise and timely fashion is a powerful asset. If gains in federal aid to education are to be sustained, the education community will be constantly challenged to collaborate, inform, and participate.

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